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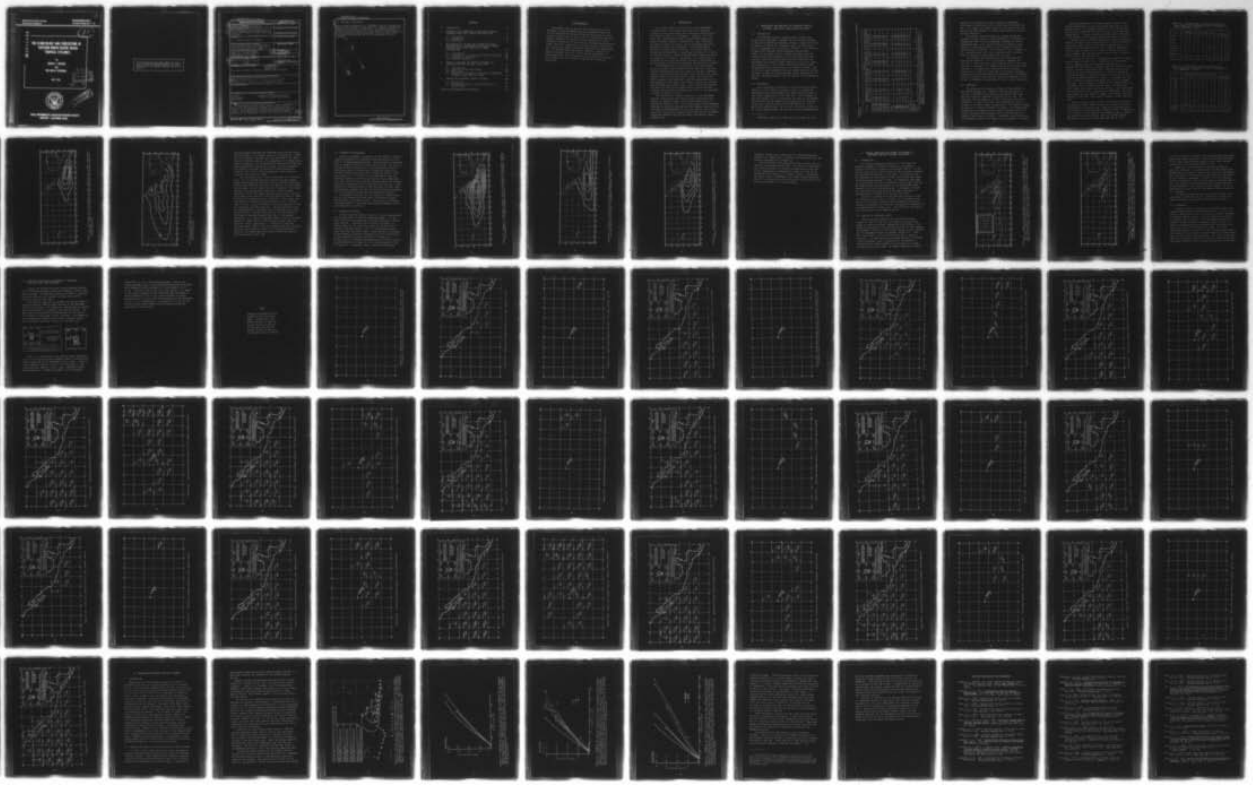

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THE CLIMATOLOGY AND FORECASTING OF EASTERN NORTH PACIFIC OCEAN TROPICAL CYCLONES

by

ROBERT J. RENARD
and
WILLIAM N. BOWMAN

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The eastern tropical North Pacific Ocean (EASTROPAC) is one of the most prolific regions for tropical cyclone activity, considering the limited area and season of occurrence. This publication presents operationally usable statistics on frequency, initial and terminal positions, NWRT Page

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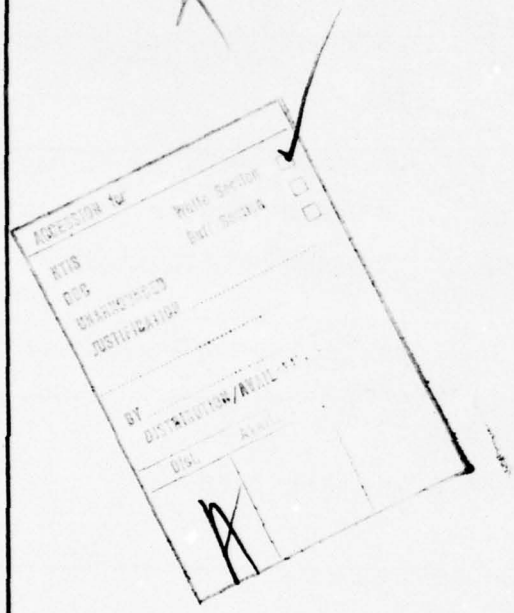
20. Abstract (continued)

track, speed and duration of EASTROPAC tropical cyclones, as derived from a recent 10-year period of adequate operational satellite surveillance, 1965-1974. The current status of forecasting these cyclones is highlighted by recent statistics on the accuracy of analog forecasts of the cyclone tracks. A selected bibliography and list of references is also included.



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1. INTRODUCTION

The eastern tropical North Pacific Ocean (EASTROPAC) is widely held to be a region most prolific in tropical cyclone activity, considering the limited area and period of occurrence (mid-May to mid-November). However, it is only since 1965, with weather satellite observation capability added to sporadic weather reconnaissance, that information on numbers, stages, and tracks can be considered reasonably complete, reliable and homogeneous. The climatological behavior of these tropical cyclones, as derived from the 10-year period 1965-1974, is described in Sections 2, 3 and 4. The current status of forecasting EASTROPAC tropical cyclones is discussed in Section 5. In general, this publication is designed to assist the operational forecaster and planner in an area where climatological estimates are especially valuable.

The EASTROPAC area, as defined for this study, encompasses the ocean region bounded by North America on the east and the International Date Line (180°) on the west, although tropical cyclone tracks may extend across the 180° line to the western sector of the North Pacific Ocean. The south and north boundaries are dynamically and thermodynamically set by the atmospheric and oceanic environment in which the cyclones form and move (Gray, 1968, 1975). Hence, 5N and 35N complete the bounds of the area considered here, although anomalous tropical cyclone activity beyond these limits is not precluded, as noted in Sections 3 and 4.

The source of all cyclone statistics is the EASTROPAC tropical cyclone data bank (1949 to date) furnished to the authors on magnetic tape by the National Weather Service Detachment, Asheville, NC. The climatological 12-hour movement analyses in Section 4 were derived from computerized statistics furnished by the NWSD Asheville; further quality control processing of the data was accomplished at the Naval Environmental Prediction Research Facility and Naval Postgraduate School, Monterey, CA.

2. FREQUENCIES AND DURATIONS OF EASTROPAC TROPICAL CYCLONES (1965-1974): WHOLE-AREA STATISTICS

2.1 INTRODUCTION

The EASTROPAC tropical cyclone season extends from mid-May to mid-November, although the less reliable records of the period 1949-64 do indicate a tropical cyclone occurring as early as 21 March (as a tropical storm, in 1951) and as late as 6 December (as a hurricane, in 1957).* The statistics on whole-area tropical cyclone frequency and duration (Table 2-1) are given for all tropical cyclones; they are listed by the three categories of tropical depression (D), tropical storm (S) and hurricane (H), and stratified into semimonthly and overall season intervals as well as by years. The categories D, S and H refer to the most intense stage attained during the life history of a tropical cyclone. All of the life cycle (duration) of a particular tropical cyclone has been assigned to the half-monthly period during which it was first observed (usually, but not always, in the depression stage).

2.2 FREQUENCIES

The climatological expectation, derived from the period 1965-74, is 15.7 tropical cyclones a year, all categories considered, while the frequency for named cyclones (those in the S and H categories) is 14.5 per year. The S category is the most common, with 7.9 occurrences per year on the average. These figures may be compared to an average of 9.0 tropical cyclones per year derived from the 1949-64 period, all of which were classified as S or H. Such a figure is likely to be a gross underestimate, due both to a lack of documentation,

---

*EASTROPAC tropical cyclones were first named in 1960.

Table 2-1. Frequency and average duration statistics for tropical cyclones, EASTROPAC, 1965-74.

Period	Category							
	Depressions (D)		Tropical Storms (S)		Hurricanes (H)		All Tropical Cyclones	
	No. Per Year	Avg. Dur. (days)	No. Per Year	Avg. Dur. (days)	No. Per Year	Avg. Dur. (days)	No. Per Year	Avg. Dur. (days)
16-31 May	0.10	0.5	0.10	4.4	0.12	5.9	0.32	4.2
1-15 Jun	0.10	4.0	0.50	3.5	0.33	8.6	0.93	5.8
16-30 Jun	0.00	0.0	0.74	3.4	0.35	4.1	1.09	3.5
1-15 Jul	0.10	3.2	0.80	5.8	0.43	8.2	1.33	6.4
16-31 Jul	0.20	5.7	1.23	4.8	0.62	8.7	2.05	6.2
1-15 Aug	0.30	1.1	0.90	4.0	0.67	9.0	1.87	5.9
16-31 Aug	0.10	2.0	0.75	5.8	1.60	7.2	2.45	6.5
1-15 Sep	0.10	1.0	0.81	6.1	1.03	6.7	1.94	6.3
16-30 Sep	0.00	0.0	0.89	5.1	0.45	7.0	1.34	6.1
1-15 Oct	0.20	1.0	0.17	1.2	0.92	7.5	1.29	5.7
16-31 Oct	0.00	0.0	0.78	4.7	0.08	0.0	0.86	4.7
1-15 Nov	0.00	0.0	0.22	4.9	0.00	0.0	0.22	4.9
16 May - 15 Nov	1.2	2.9	7.9	4.8	6.6	7.6	15.7	5.8
1965	0	--	9	6.1	1	6.0	10	6.0
1966	0	--	6	3.3	7	6.9	13	5.2
1967	0	--	11	5.6	7	6.9	18	6.1
1968	1	2.0	12	5.9	6	7.4	19	6.1
1969	4	1.4	6	4.4	4	6.8	14	4.2
1970	0	--	14	4.5	4	9.2	18	5.5
1971	0	--	5	5.0	12	7.4	17	6.7
1972	0	--	5	4.6	7	10.2	12	7.9
1973	0	--	5	3.4	7	8.6	12	6.4
1974	7	3.9	6	3.5	11	6.3	24	4.9
1965-1974	12	2.9	79	4.8	66	7.6	157	5.8
Category Days Per Year	3.5		37.9		50.2		91.6	

Note: The frequency is assigned proportionately to the half-monthly periods of occurrence; the duration is assigned only to that half-monthly period containing the first day of occurrence. This accounts for the apparent inconsistency of 0.08 hurricanes per year in the period 16-31 October, while the average duration is 0.0 days.

especially on depressions, and to generally inadequate surveillance in the years prior to the operational-satellite era. This comparison clearly justifies the use of only the period from 1965 onwards for establishing EASTROPAC tropical cyclone statistics.

The tropical cyclone season has a rather broad peak frequency period; there is little difference in semimonthly frequencies from 16 July-15 September although the actual semimonthly peak, 2.45, occurs during 16-31 August, mostly because of the high incidence of the H category (1.60 per year) during this period. The incidence of the S category is at a maximum during 16-31 July, causing a minor secondary peak in overall occurrence during this period.

The frequency distributions for the individual years show marked anomalies. All of the tropical depressions occurred in the three years 1968, 1969 and 1974; in the years 1965-70, an average of 9.7 tropical storms and 4.8 hurricanes occurred -- in comparison to the period 1971-74 when an average of 5.2 tropical storms and 9.2 hurricanes occurred. Subjectivity in the observation and documentation of EASTROPAC tropical cyclones may account for some of the apparent variability in frequency of occurrence of the D, S and H categories.

2.3 DURATIONS

The duration of a tropical cyclone has been defined to the nearest quarter-day. However, duration statistics in Tables 2-1 through 2-4 are given to the nearest tenth-day, and thus should be regarded as accurate to $\pm$0.1 day. As expected, the H category is the most long-lived, lasting an average of 7.6 days, while the S and D categories last an average of 4.8 and 2.9 days, respectively. The overall average duration of a tropical cyclone is 5.8 days. The relationship of duration to frequency is not direct, although overall the central two-month high-frequency period also produces the longest-lived tropical cyclones. Hurricanes occurring during the semimonthly period 1-15 August last an average of 9.0 days.

With few exceptions, hurricanes outlast storms, which outlast depressions, in every half-month period and in the overall season. Hurricanes occurring in 1970 and 1972 were particularly long-lived (9.2 and 10.2 days, on the average, respectively). Tropical cyclones that occurred in 1972 were, on the average, of the longest duration recorded (7.9 days).

Looking again at the two periods with unusual frequencies, 1965-70 and 1971-74, the durations of the S and H categories tend to be longer during the period of high frequency. For example, the average duration of the S category decreases from 4.8 days in 1965-70 to 4.1 days in 1971-74, while for the H category the duration value increases from 7.2 days in 1965-70 to 8.1 days in 1971-74.

The figure in Table 2-1 indicating the number of tropical cyclone days per year, 91.6 -- comprising 3.5 D category, 37.9 S category, and 50.2 H category days per year -- is greater than the number of calendar days with tropical cyclone activity reported since two or more tropical cyclones occasionally do exist contemporaneously. Table 2-2 stratifies the average number of days with single (1) and multiple (2-5) tropical cyclone occurrences by month. A 'calendar day' may have a single or multiple occurrence, but is still counted only once. When frequency is viewed in this manner, there is an average of 70.7 cyclone days per year. In the period 26-27 August 1974, there were five cyclones -- four hurricanes and one tropical storm -- coexisting in EASTROPAC. Multiple occurrences are most common in August; for example, four were reported at one time in the month of August in both 1972 and 1974.

Table 2-3 gives further details on multiple occurrences by showing the total number of days with single and multiple occurrences by individual year. Multiple occurrences were most frequent in 1974 and least frequent in 1969. Although it is not shown, the existence of an EASTROPAC tropical cyclone was reported on every calendar date from 30 May through 8 November, even in the short time span 1965 to 1974.

Table 2-2. Average number of days with single (1) and multiple (2-5) tropical cyclone occurrences by month, EASTROPAC, 1965-74.

Month	Concurrent Number of Tropical Cyclones					Total No. Days
	1	2	3	4	5	
May	0.9	0	0	0	0	0.9
June	8.8	0.6	0	0	0	9.4
July	10.1	4.2	0.8	0	0	15.1
August	9.8	6.0	1.7	0.4	0.2	18.1
September	11.8	2.2	1.2	0.1	0	15.3
October	10.0	0.7	0	0	0	10.7
November	1.2	0	0	0	0	1.2
Total	52.6	13.7	3.7	0.5	0.2	70.7

Table 2-3. Total number of days with single (1) and multiple (2-5) tropical cyclone occurrences by year, EASTROPAC, 1965-74.

Year	Concurrent Number of Tropical Cyclones					Total No. Days
	1	2	3	4	5	
1965	42.5	9.8	0	0	0	52.3
1966	36.0	12.0	5.5	1.0	0	54.5
1967	68.2	10.8	6.8	0	0	85.8
1968	62.0	21.0	5.2	0	0	88.2
1969	52.5	1.0	0	0	0	53.5
1970	76.2	11.8	0	0	0	88.0
1971	49.8	28.2	2.2	0	0	80.2
1972	39.0	10.5	10.2	0.8	0	60.5
1973	30.5	16.5	4.2	0	0	51.2
1974	68.8	15.5	2.8	3.5	1.8	92.4
Ten Year Total	525.5	137.1	36.9	5.3	1.8	706.6

Table 2-4 provides further insight into the "duration" problem of EASTROPAC tropical cyclones. It shows that nearly two-thirds (61%, 2.9 days) of the life history of an average tropical storm is spent in the storm stage, while nearly equal amounts of time of an average hurricane are spent in the storm stage (43%, 3.3 days) and hurricane stage (35%, 2.6 days). In the case of the S category, there are many cases in which all or almost all of the life history was observed in the storm stage; this would suggest that the depression stage was very minimal, but perhaps, in reality, not totally absent (as occurred with tropical storms Doreen in 1965, Ilsa in 1967, and Aletta in 1974; the existence of a depression stage was not recorded for any of these storms). For the tropical cyclones classified as hurricanes, a storm stage is invariably observed.

Table 2-4. Portions of the life history of the average tropical cyclone spent in each of the three stages: depression, storm and hurricane; EASTROPAC, 1965-74.

Tropical Cyclone Category	Time in Stage Documented as:		
	Depression	Storm	Hurricane
Depression	100% 2.9 days	--	--
Storm	39% 1.9 days	61% 2.9 days	--
Hurricane	22% 1.7 days	43% 3.3 days	35% 2.6 days

3. DISTRIBUTION OF INITIAL AND TERMINAL POSITIONS AND FREQUENCY OF OCCURRENCE OF EASTROPAC TROPICAL CYCLONES (1965-1974): ANALYSES OF AREAL DISTRIBUTIONS

3.1 INTRODUCTION

Areal distributions of occurrence of tropical cyclones in the eastern North Pacific Ocean during the period 1965-74 are presented and discussed in this section. The initiation and termination points were determined from documentation furnished by the National Climatic Center, Asheville, NC. Consistent with the amount, period and validity of the data base, the position analyses are shown relative to 5° latitude-longitude squares. A tropical cyclone was counted once only for each occurrence in a square, regardless of the length of time or track in that square. Such positions represent the first and last time of detection of a tropical cyclone (usually in the depression or tropical storm stage of intensity). Almost certainly, such tropical circulations existed as disturbances (i.e., areas of organized convection) for some time both prior to the initiation times and after the termination times considered here.

3.2 DISTRIBUTION OF INITIAL AND TERMINAL POSITIONS

Figures 3-1 and 3-2 show analyses of initiation and termination positions by means of constant percentage envelopes of 25, 50, 75 and 95 percent. The 25% envelope may be considered to bound the smallest area containing 25% of the initial (Figure 3-1) and final (Figure 3-2) positions. The remaining isopleths should be considered in a similar wav.

The prime area of initiation lies between 10N and 15N from 180 to 480 miles off the west coast of the North American continent. The two 5° latitude-longitude squares with the maximum number of initiation positions are in the area

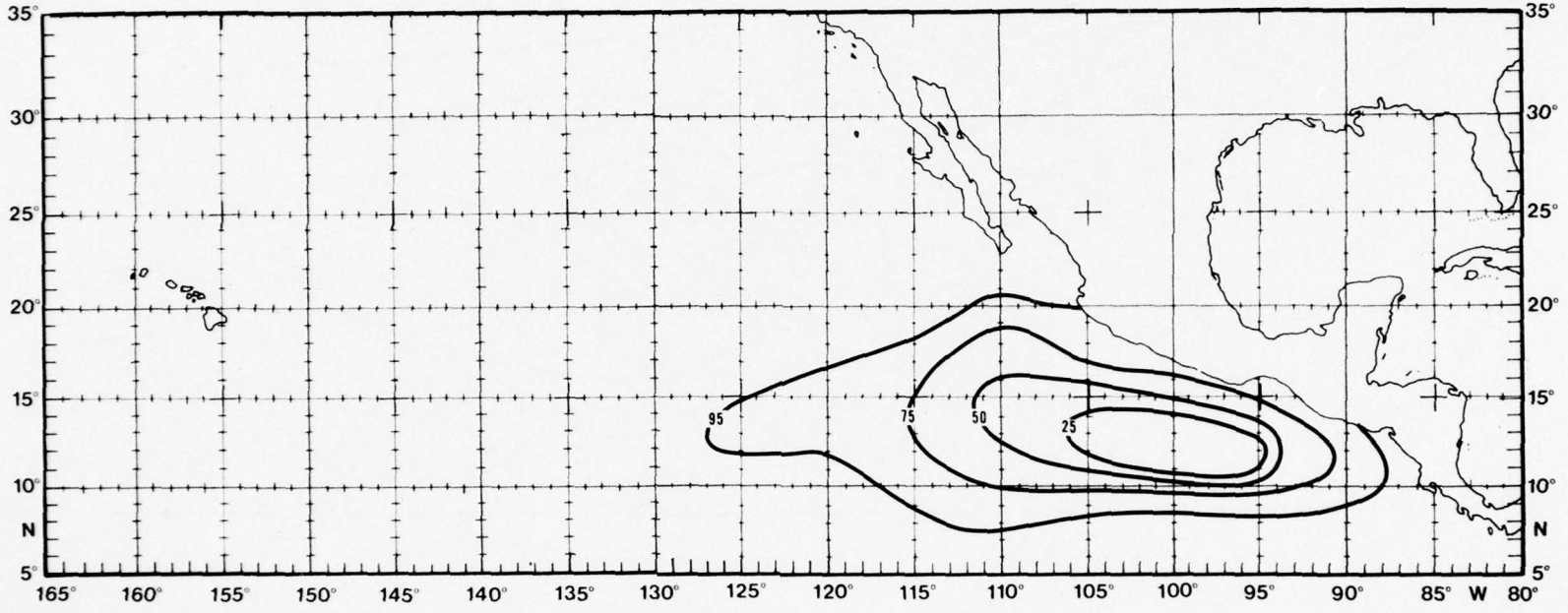


Figure 3-1. Initiation areas of tropical cyclones (depressions, storms, hurricanes) in EASTROPAC, 1965-74. Each isoline encloses specified percentage number of initial positions.

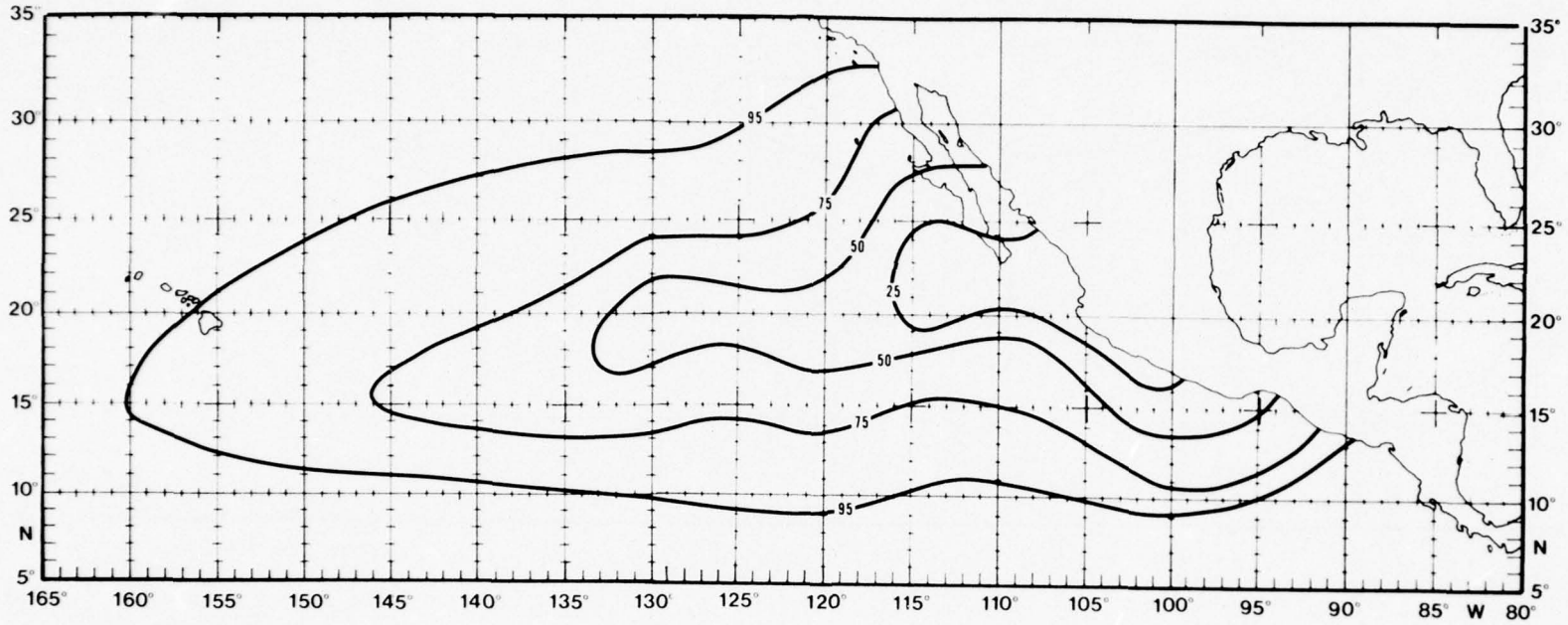


Figure 3-2. Termination areas of tropical cyclones (depressions, storms, hurricanes) in EASTROPAC, 1965-74. Each isoline encloses specified percentage number of terminal positions.

10N-15N, between 95W-100W and 100W-105W, each with 25 initiation positions in the 10-year period of consideration. Nearly 50% of all tropical cyclones are first detected in the zone 10N-15N, 95W-110W, usually in the depression or tropical storm stage of intensity. No initiation positions west of 135W have been documented in the period of study. The most southerly and northerly latitudes of reported initiation positions (1965-74) are 7.7N (a tropical depression, 1974) and 20.4N (tropical storm Candice, 1965).

The termination area is more diffuse than the initiation area. The 5° latitude-longitude squares with the maximum number of reported terminal positions are 15N-20N, 100W-105W and 20N-25N, 110W-115W, each with 13 reports, closely followed by the square 20N-25N, 105W-110W with 12 reports. From these squares, the terminal zone bulges north along the Baja Peninsula and the continental Mexican coast, as well as westward along a zone from 15N to 22.5N, becoming diffuse by 135W. Although it is beyond the area considered in this study, the most westerly termination point reported is that of Sarah, 1967, at 151E -- some 75 degrees of longitude westward of the most westward initiation position. Terminal positions have not been reported at latitudes north of northern Baja in the period 1965-74. The most southerly and the most northerly latitudes of reported terminal positions in the Western Hemisphere (i.e., east of longitude 180W) are 8.5N (a tropical depression, 1974) and 31.9N (hurricanes Katrina, 1967 and Hyacinth, 1972), respectively. It should be noted that hurricane Sarah, 1967, at her last reported and most northerly position, was located at 36.4N in the Eastern Hemisphere. Section 4.3 provides additional detail concerning reported terminal positions over land.

3.3 FREQUENCY OF OCCURRENCE

Figure 3-3 presents an analysis of the number of 1965-74 tropical cyclones of all categories passing through or into each 5° latitude-longitude square. The most heavily traversed area is between 15 and 17.5N, from 105W to 115W. The axis of maximum traversal relates well to the concentrated area of initiation south of 15N and east of 105W (see Figure 3-1), and the area of termination near latitude 15N west of 120W (see Figure 3-2). If Figure 3-3 was modified to show the traversal statistics for the storm and hurricane categories only, the isoline values would be generally about one isopleth unit less in the area east of 140W, with the major axis a few degrees of latitude poleward in the area east of 110W. These considerations suggest that the storm and hurricane categories have a track further north than the depression category.

As expected, the major axis in Figure 3-3 relates quite well to the orientation of the areal vector mean tropical cyclone tracks (see Figure 4-23). This subject is analyzed in greater detail in the track and speeds-of-movement statistics presented in Section 4.

3.4 FORMATION POTENTIAL

The 25% isopleth shown in Figure 3-1 covers approximately one and two-fifths 5° latitude-longitude squares. In this area, 39 tropical cyclones were initially detected in the 10 years 1965-74 -- equivalent to 78 tropical cyclones in a 20-year period or 56 tropical cyclones per 20 years per 5° latitude-longitude square. This is a considerably higher value than that implied by Gray's (1975) analysis of tropical cyclone formation potential (Figure 3-4) or the verification of the potential with data from 1952-71 (Figure 3-5). Further, Gray's isopleth of observed maximum initial tropical cyclone detection in Figure 3-5 is to the northwest of that in Figure 3-1. In general, Gray's isolines of formation

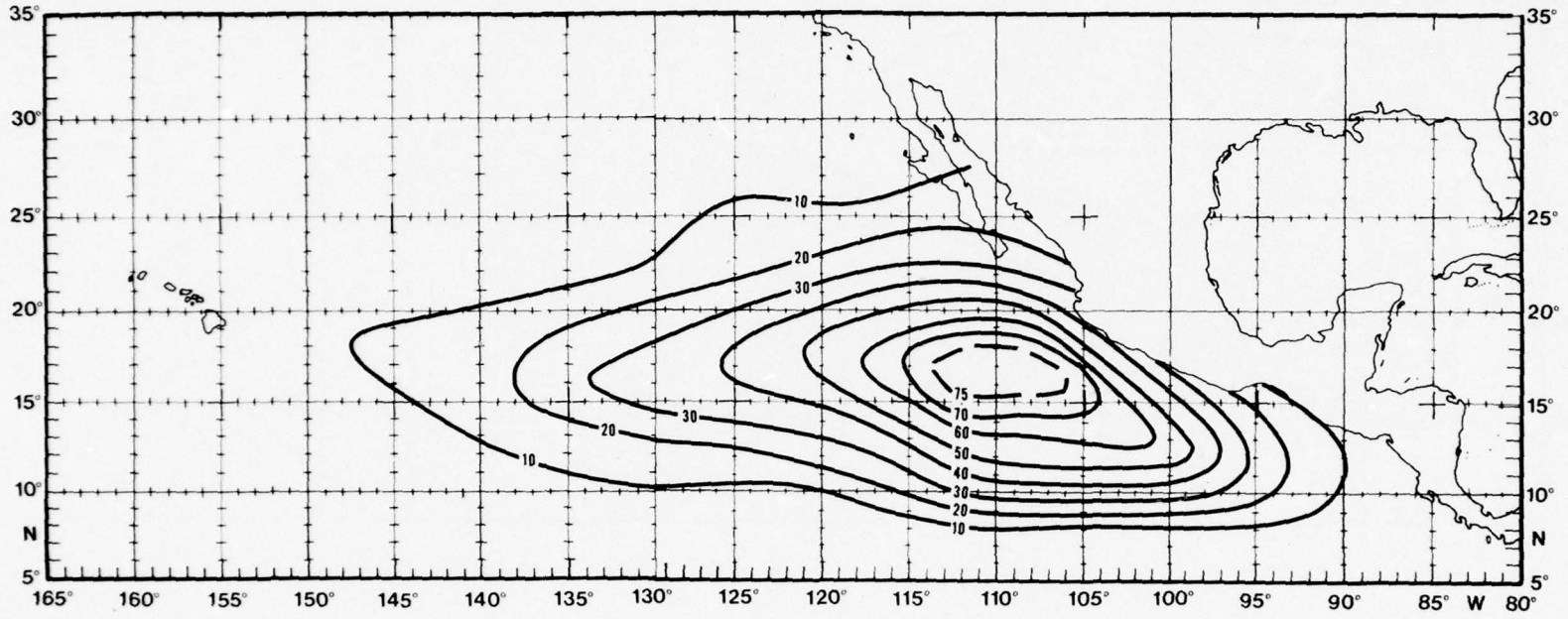


Figure 3-3. Number of individual tropical cyclone occurrences (depressions, storms, hurricanes) per 5° latitude-longitude square per 10 years in EASTROPAC, 1965-74.

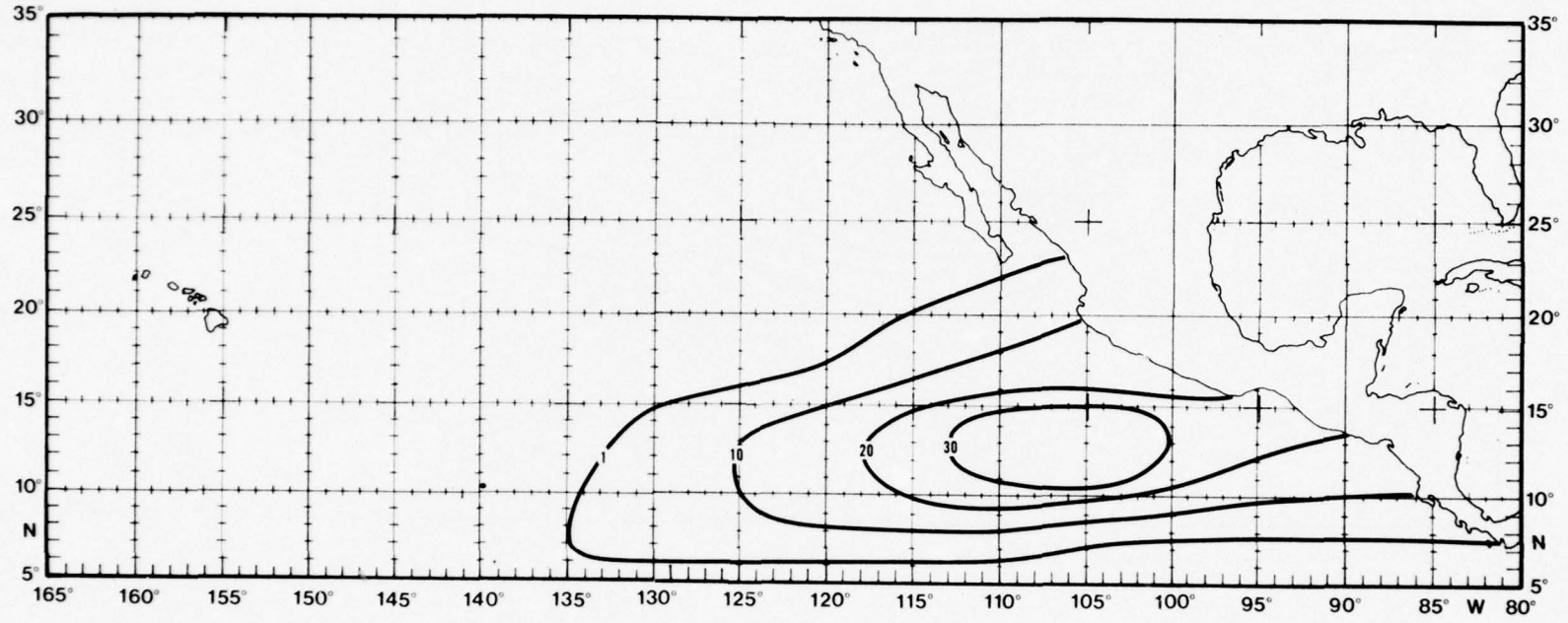


Figure 3-4. Potential tropical cyclone origin frequency (number per 5° latitude-longitude square per 20 years) in EASTROPAC (from Gray, 1975).

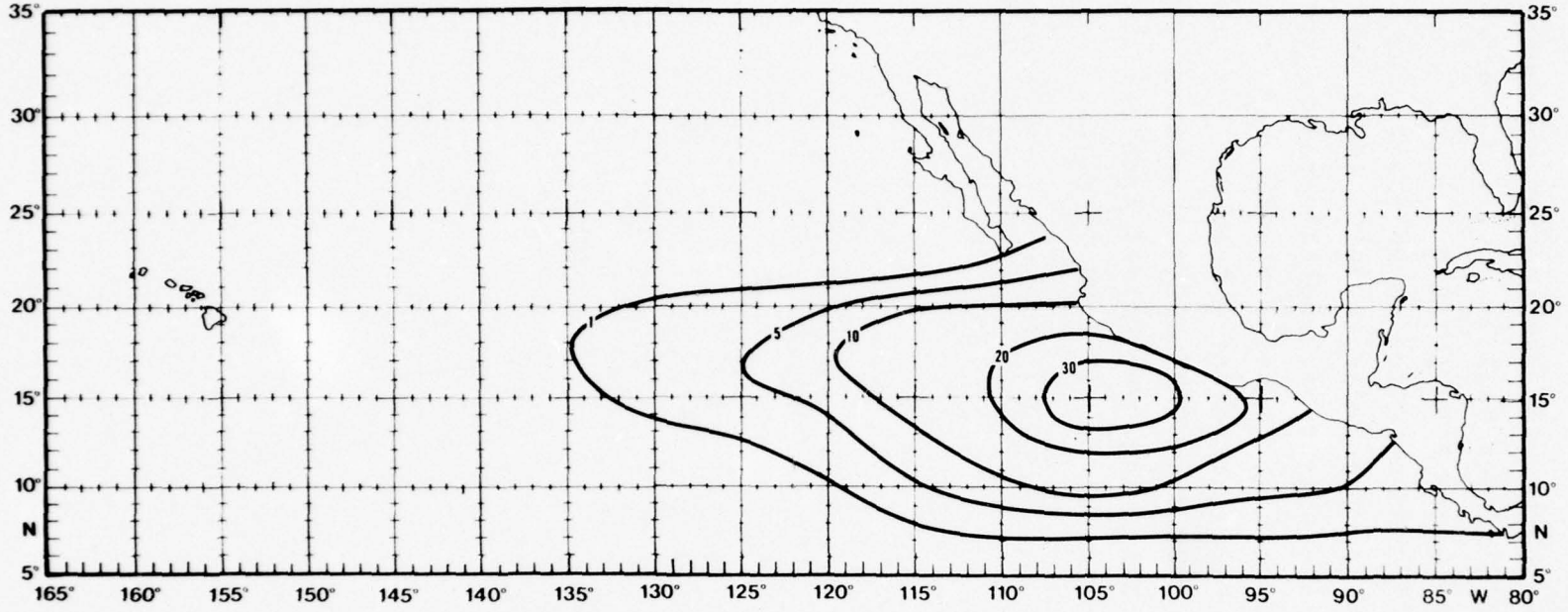


Figure 3-5. Observed tropical cyclone origin frequency (number per 5° latitude-longitude square per 20 years) in EASTROPAC (from Gray, 1975).

potential (Figure 3-4), rather than his observed formation (Figure 3-5), agrees best in position and orientation with the analysis presented here (Figure 3-1).

The differences cited above may be due to Gray's use of data for the period prior to 1965. This period is notoriously low in the assessment of tropical cyclone activity and, due to the inadequacies of observation, prone to a time lag in detecting the existence of a tropical cyclone. Considering the normal tracks in EASTROPAC, the latter problem generally results in assigning the initial tropical cyclone position to the west-northwest of its true location.

4. TRACKS, DIRECTIONS AND SPEEDS OF MOVEMENT OF EASTROPAC TROPICAL CYCLONES (1965-1974)

4.1 INTRODUCTION

This section presents an analysis of the tracks and speeds of movement of tropical cyclones in the eastern tropical North Pacific Ocean for the period 1965-74. In this period, high quality satellite data allows relatively accurate and detailed track analyses to be made. The analyses cover the geographical area from 5N to 35N, and from the west coast of North America westward to 180W. No attempt has been made to follow further the very few tropical cyclones that crossed the 180W meridian moving westward, or to incorporate these movements into the forecasting guide. Five-degree latitude by five-degree longitude analyses has been performed, in consonance with the quality of the available data.

Section 4.2 examines only the hurricane portions of the 157 tropical cyclone tracks. Section 4.3 is devoted to the tracks of all tropical cyclones which underwent recurvature. Section 4.4 analyzes the directions and speeds of movements of all named tropical cyclones (i.e., 145 storms and hurricanes) that occurred during the 1965-74 period.

4.2 ANALYSIS OF HURRICANE TRACKS

During the period 1965-74, 66 hurricanes occurred. Figures 4-1 and 4-2 show only the tracks of the hurricane stages of tropical cyclones categorized as hurricanes. The tracks are presented in two calendar periods: 16 July through 15 September (Figure 4-1), and 16 May through 15 July combined with 16 September through 15 November (Figure 4-2). Thus, the 'high season' (i.e., more active period) is shown in Figure 4-1. In some cases the hurricane portion of the track is not continuous; such a discontinuity, indicated by a scalloped line, usually denotes the existence of an intervening tropical storm stage. An example apparent in Figure

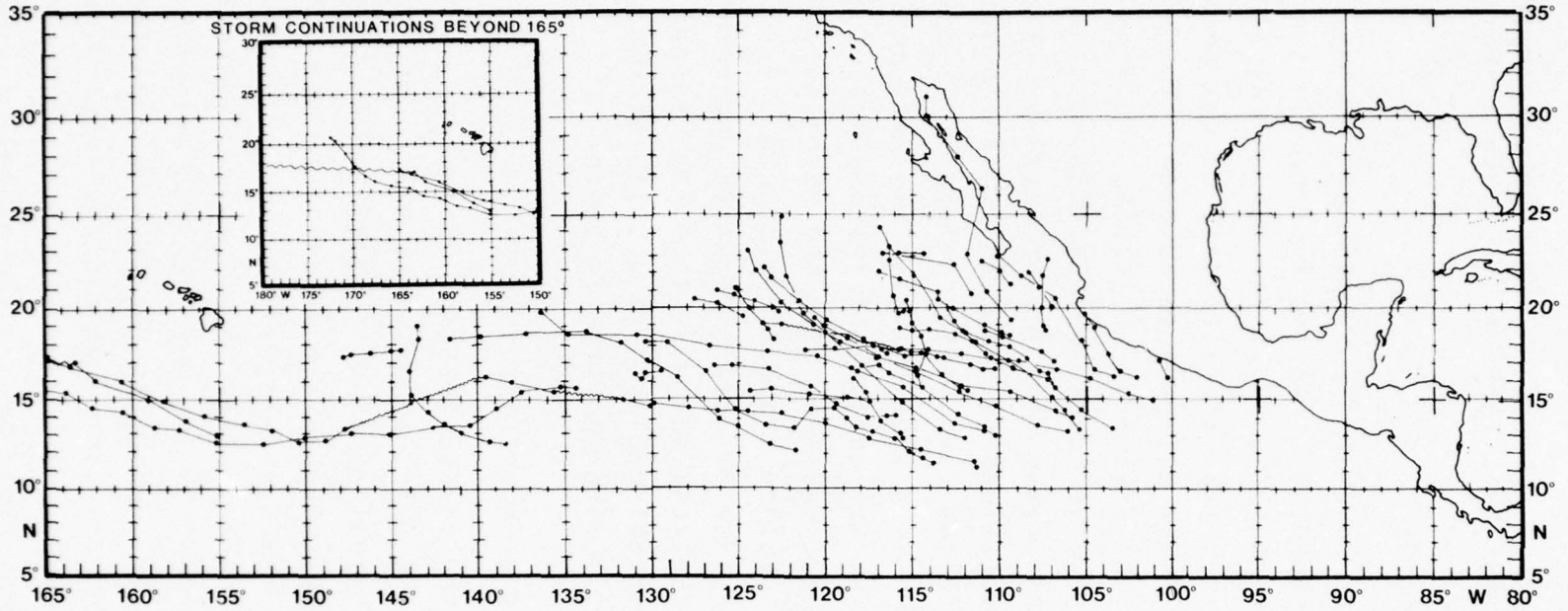


Figure 4-1. Composite hurricane-stage tracks of tropical cyclones (solid lines, with positions at 0000 and 1200 GMT), 16 July-15 September, in EASTROPAC, 1965-74. Wavy line indicates interim period of depression and/or tropical storm stage separating hurricane stages in individual cyclone.

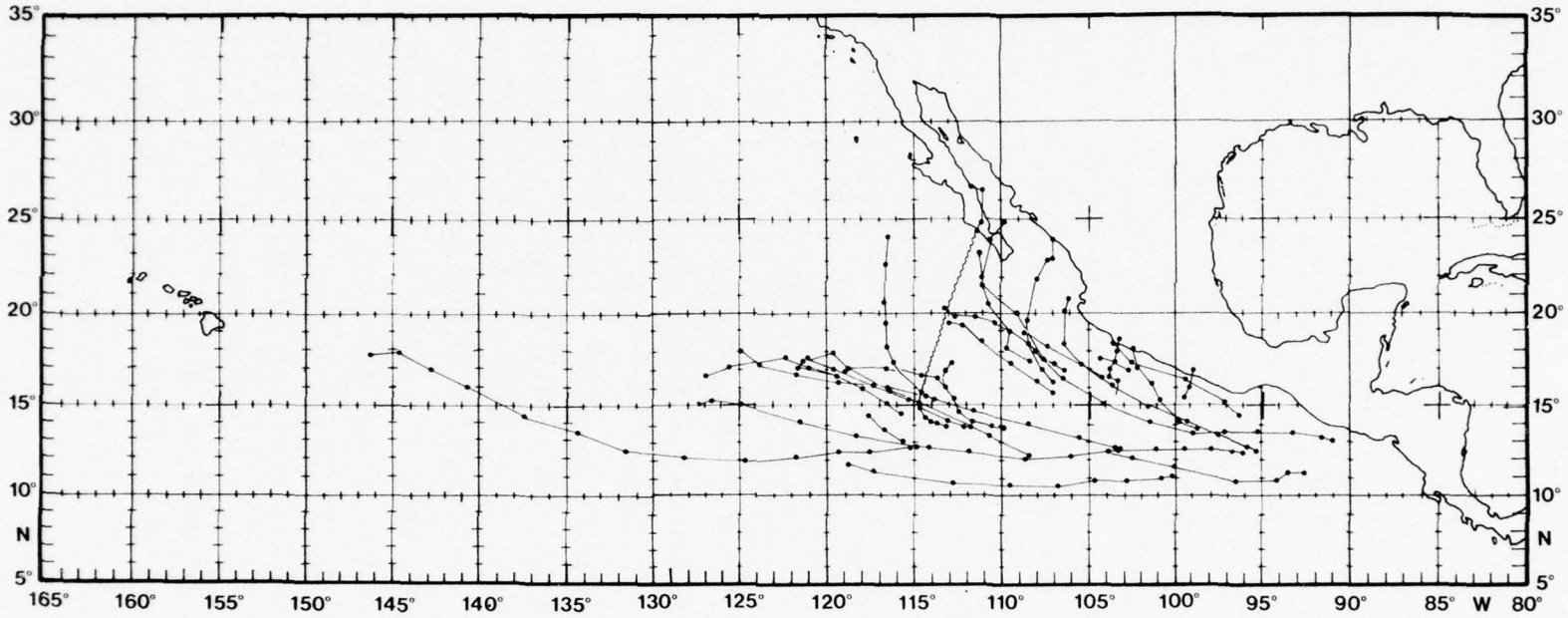


Figure 4-2. Composite hurricane-stage tracks of tropical cyclones (solid lines, with positions at 0000 and 1200 GMT), 16 May-15 July and 16 September-15 November, in EASTROPAC, 1965-74. Wavy line indicates interim period of depression and/or tropical storm stage separating hurricane stages in individual cyclone.

4-2 is the track of an October 1967 hurricane whose hurricane-stage track begins at 14.0N, 113.0W and terminates at 26.8N, 111.7W, with a sub-hurricane stage (in this case, tropical storm) from 15.1N, 114.6W to 24.4N, 111.2W.

Figures 4-1 and 4-2 show that tropical cyclones of hurricane intensity in the eastern North Pacific Ocean occur predominantly eastward of 130W and that excursions westward of this longitude are confined almost exclusively to the period 16 July through 15 September. Further, the first observed point of occurrence of the hurricane stage is furthest west in the 'high season' period (being generally between 105-115W). In the remainder of the tropical cyclone season, this first-observed point occurs east of 105W about as often as west of this latitude.

The region between 15N and 20N eastward of 120W is the region most heavily traversed by hurricanes, with the more zonally-oriented tracks south of 15N and west of 120W.

4.3 RECURVATURE

Figure 4-3 shows a composite of recurvature tracks for tropical depressions, storms and hurricanes. A recurvature track is defined here as any track which includes a component of movement toward the east. The first position on each of the tracks shown in Figure 4-3 is that point at which the tropical cyclone acquired a component toward the east. It should be noted that the great majority of recurving situations occur north of 15N and east of 115W. Of the 50 recurving tropical cyclones (i.e., 32% of the 10-year sample) that occurred in the period of record 1965-74, 19 (38%) moved onto the west coast of North America. The prime coastal area affected was between 17N and 27N, where 12 tropical cyclones (24%) made landfall; three of these cyclones hit the mainland

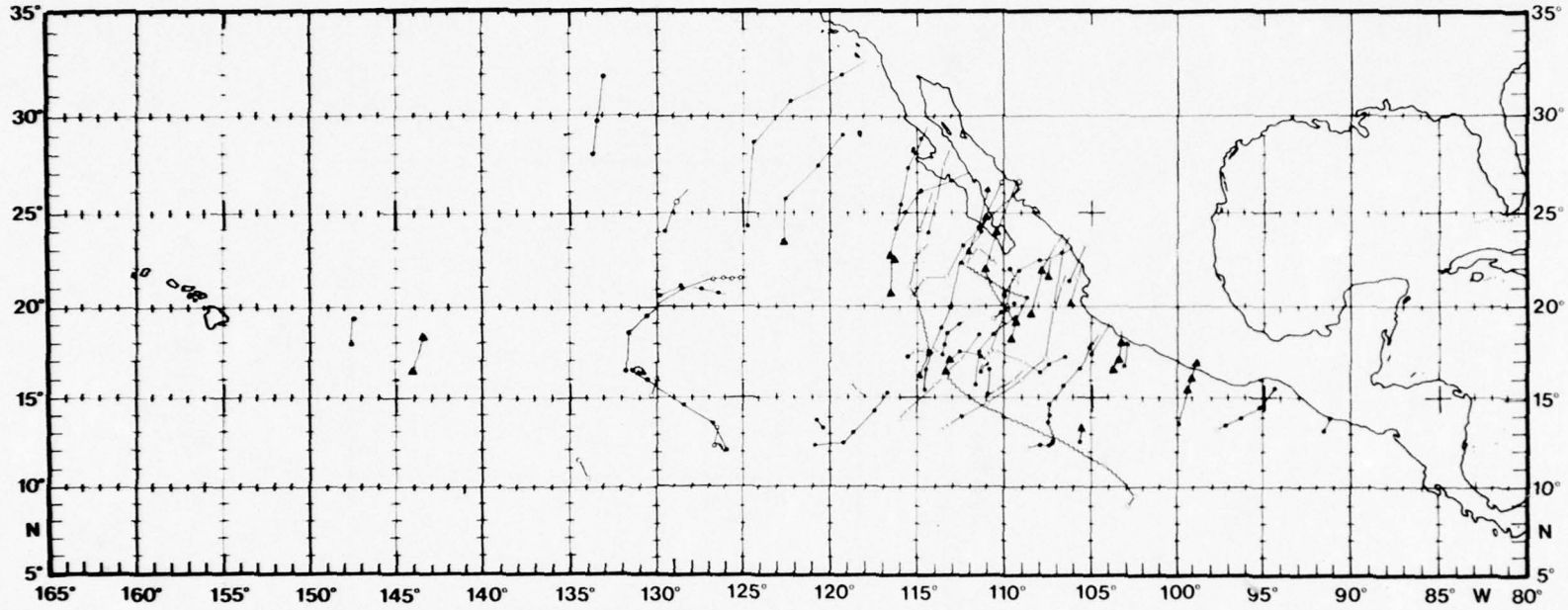


Figure 4-3. Composite recurvature tracks of all tropical cyclones in EASTROPAC, 1965-74. Wavy line indicates an interim period of westward track separating recurvature track positions of an individual cyclone. Stages coded as follows for positions at 0000 and 1200 GMT: ▲ = hurricane; ● = tropical storm; O = depression.

coast between 26N and 27N, having first crossed the lower Baja Peninsula south of 25N. Other concentrations of landfall or near-landfall occurred between 22N and 24N, and 18N and 19N.

Data in Table 4-1 indicate that 76% (38 cyclones) of the EASTROPAC recurvature cases occur in August, September and October. However, a recurving tropical cyclone has been recorded in every month from May to November. Further, recurving tropical cyclones tend to be in the tropical storm stage at the time of recurvature in the period 1965-74. On the average, one-quarter of the recurver's time is spent moving with a component toward the east.

Table 4-1. Statistics on recurving tropical cyclones, EASTROPAC, 1965-74. Month determined by first day of movement toward the east.

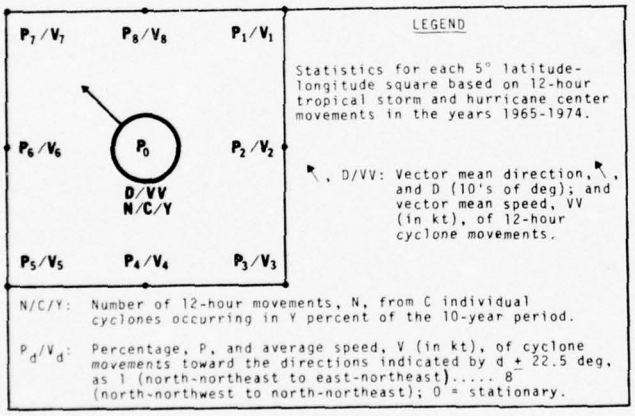
Month	Number and Percentage of all Cyclones that Recurve		Number of Recurving Cyclones According to Cyclone Stage						Average Percentage of Recurvature Time with Eastward Movement
			At Maximum Intensity			At Initial Point of Recurvature			
	No.	%	D	S	H	D	S	H	
May	2	62	0	2*	0	1	1	0	57
June	5	25	0	1	4*	2	2	1	23
July	3	09	0	2	1	1	2	0	30
Aug	8	19	1	2	5	1	5	2	13
Sep	19	58	0	9	10**	7	6	6	28
Oct	11	51	1	5	5	3	5	3	28
Nov	2	91	0	2	0	0	2	0	20
Year	50	32	2	23	25	15	23	12	25

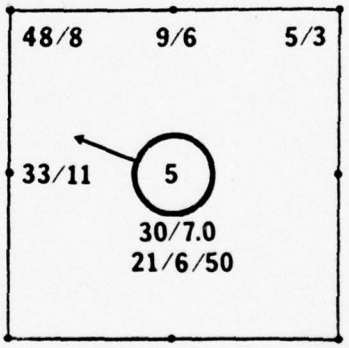
Notes: D = Depression, S = Storm, H = Hurricane.
* - Includes two cyclones with multiple recurvature tracks.
** - Includes three cyclones with multiple recurvature tracks.

4.4 DIRECTIONS AND SPEEDS OF MOVEMENT OF EASTROPAC TROPICAL STORMS AND HURRICANES

Figures 4-4 through 4-23 show 12-hour movement analyses for 5° latitude-longitude squares for bimonthly, monthly and annual periods. As previously noted in Section 4.1, analyses have been made only for tropical cyclones classified as tropical storms or hurricanes.

Each period's depiction is divided into eastern (80W to 130W) and western (130W to 180W) sections of the EASTROPAC area on facing pages. The legend for interpreting the plotted data (shown below) is included in the eastern section. The data plot and corresponding interpretation for the period 1-15 October in the square 15-20N, 115-120W, is an example of the informational content of the 12-hour tropical cyclone center movement depictions (Figures 4-4 through 4-23).





Thus, 6 (= C) hurricanes and tropical storms generated the 21 (= N) 12-hour cyclone movements (0000 to 1200 GMT and 1200 to 0000 GMT) which terminated in this square. These 21 track segments occurred in 50% (= Y) of the years in the 10-year period, 1965-74. The 21 cases generated a vector mean direction (= D and ↖) and speed (= VV) of movement

toward 300° at 7 kt. Thirty-three percent (= P_6) of the cyclone movements were in the octant bounded by the directions west-southwest to west-northwest at a mean speed of 11 kt (= V_6). Similarly, 48% (= P_7), 9% (= P_8) and 5% (= P_1) moved in the octant contained by the directions west-northwest to north-northwest at 8 kt (= V_7), north-northwest to north-northeast at 6 kt (= V_8), and north-northeast to east-northeast at 3 kt (= V_1), respectively. In addition, 5% (= P_0) of the storms and hurricanes sampled were stationary during the associated 12-hour periods.

NOTE

Figures 4-4 through 4-23 are presented on the following pages. In each pair, the western section is shown at the top as the "a" portion of the total plot and the eastern section is shown at the bottom as the "b" portion.

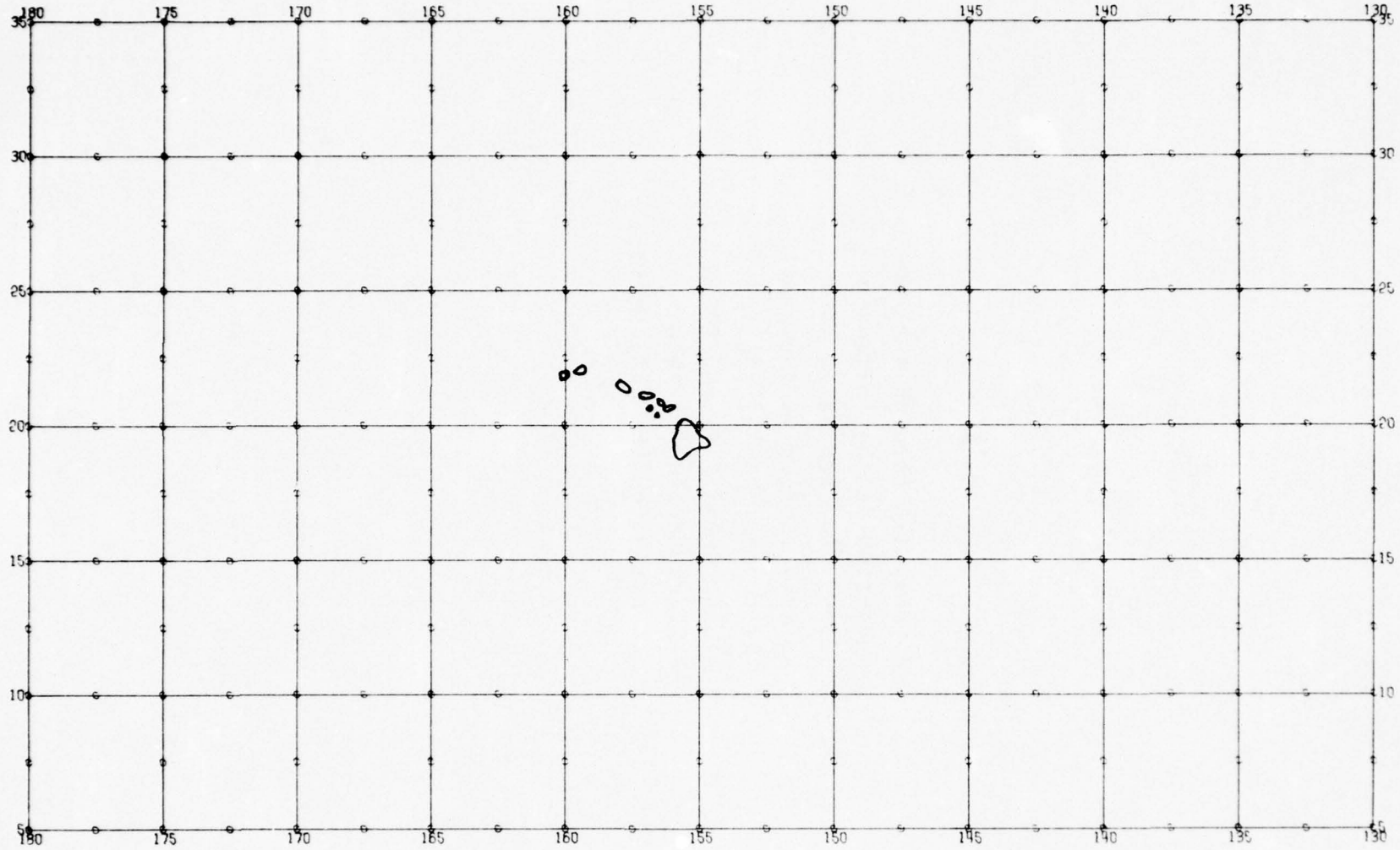


Figure 4-4a. Twelve-hour movement analysis, 16-31 May, western section. No tropical storms or hurricanes were documented during this period.

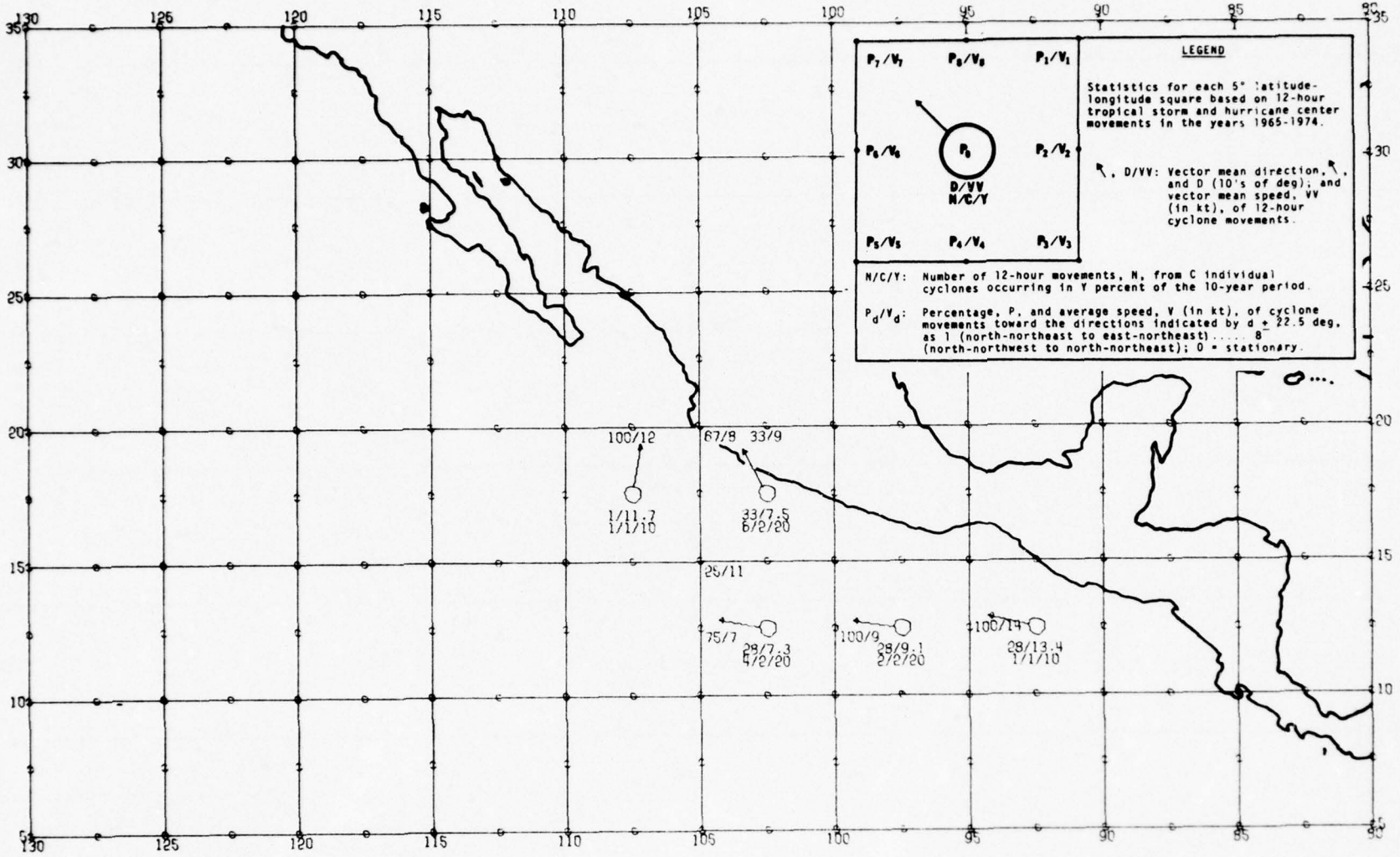


Figure 4-4b. Twelve-hour movement analysis, 16-31 May, eastern section.

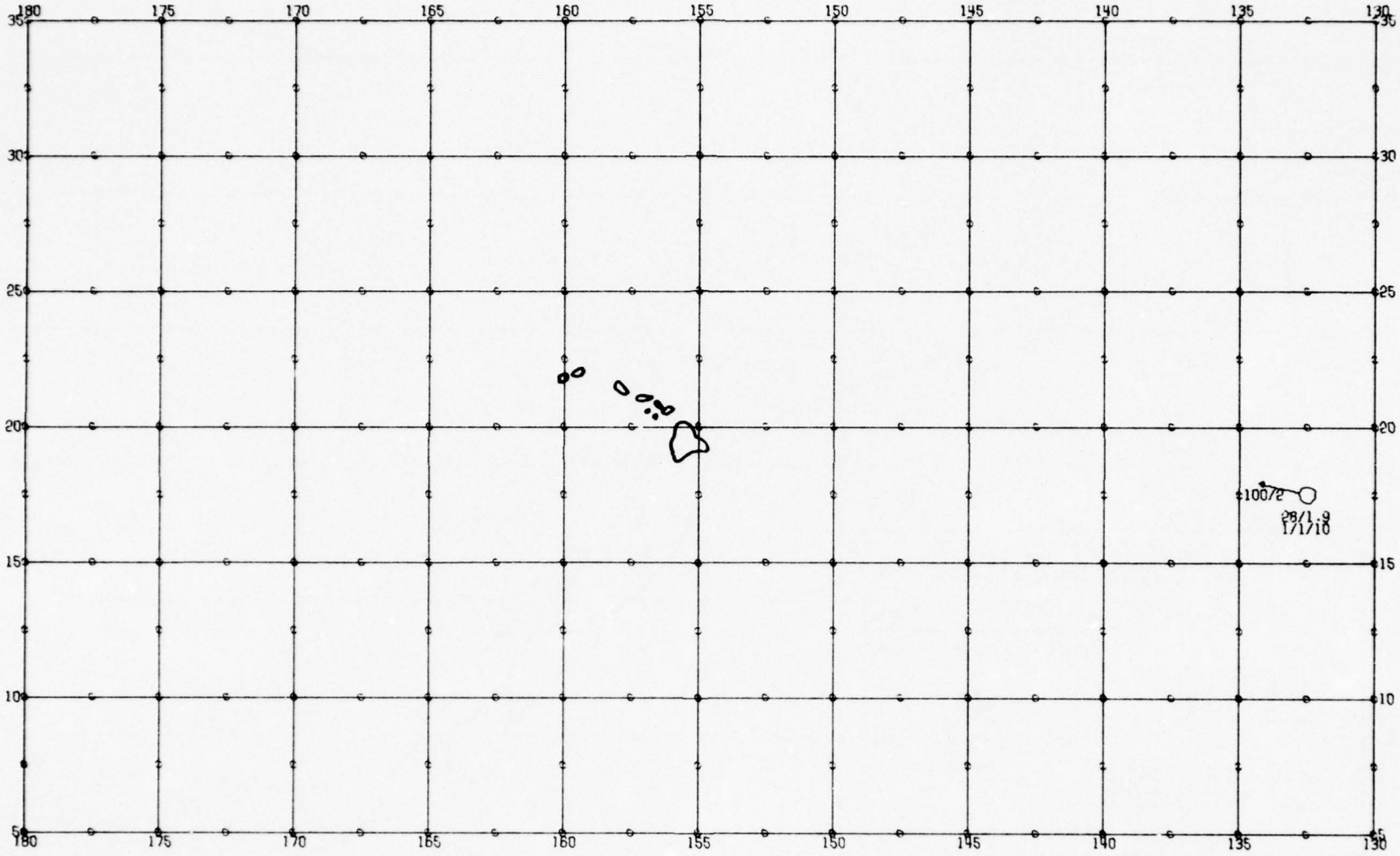


Figure 4-5a. Twelve-hour movement analysis, 1-15 June, western section.

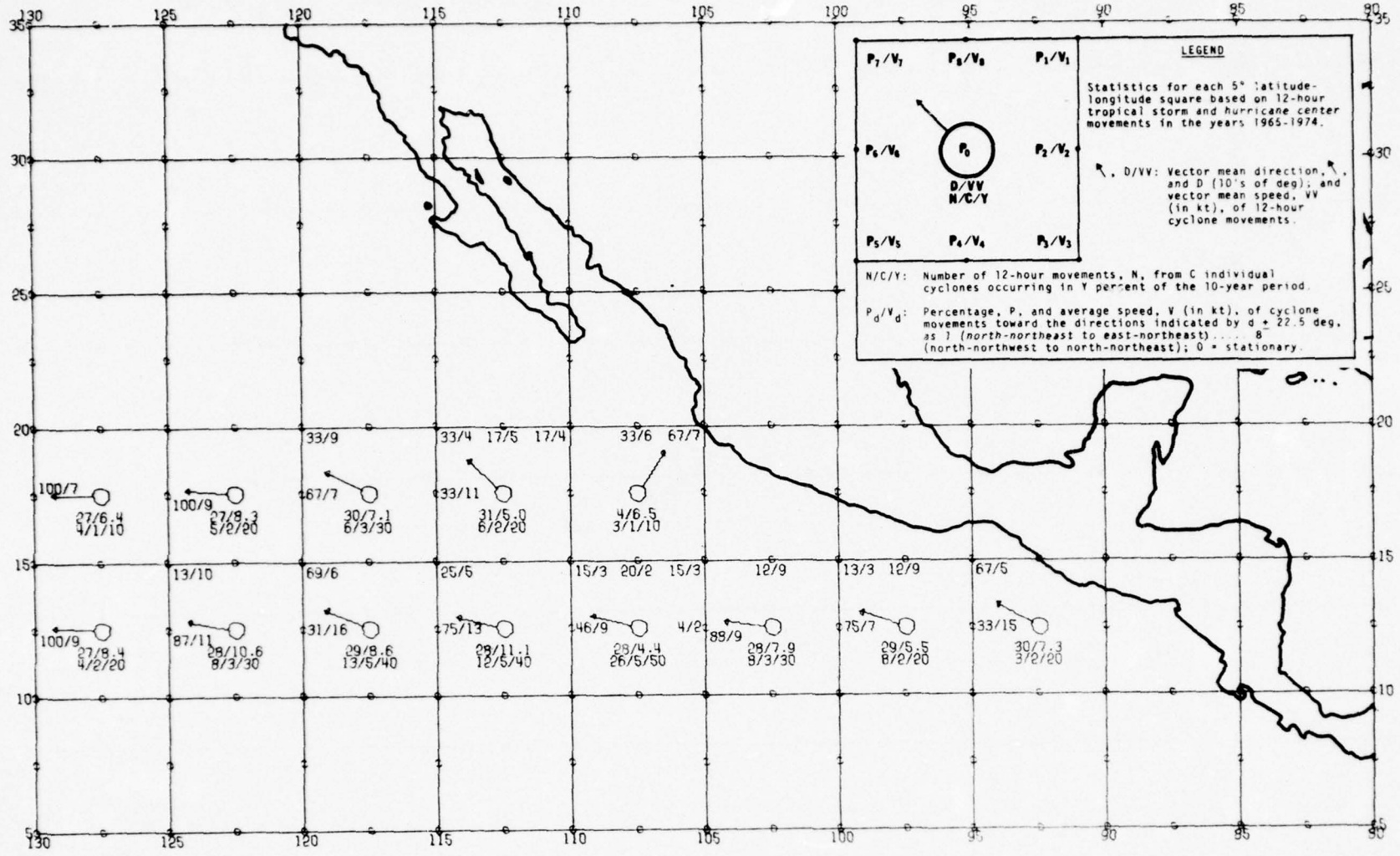


Figure 4-5b. Twelve-hour movement analysis, 1-15 June, eastern section.

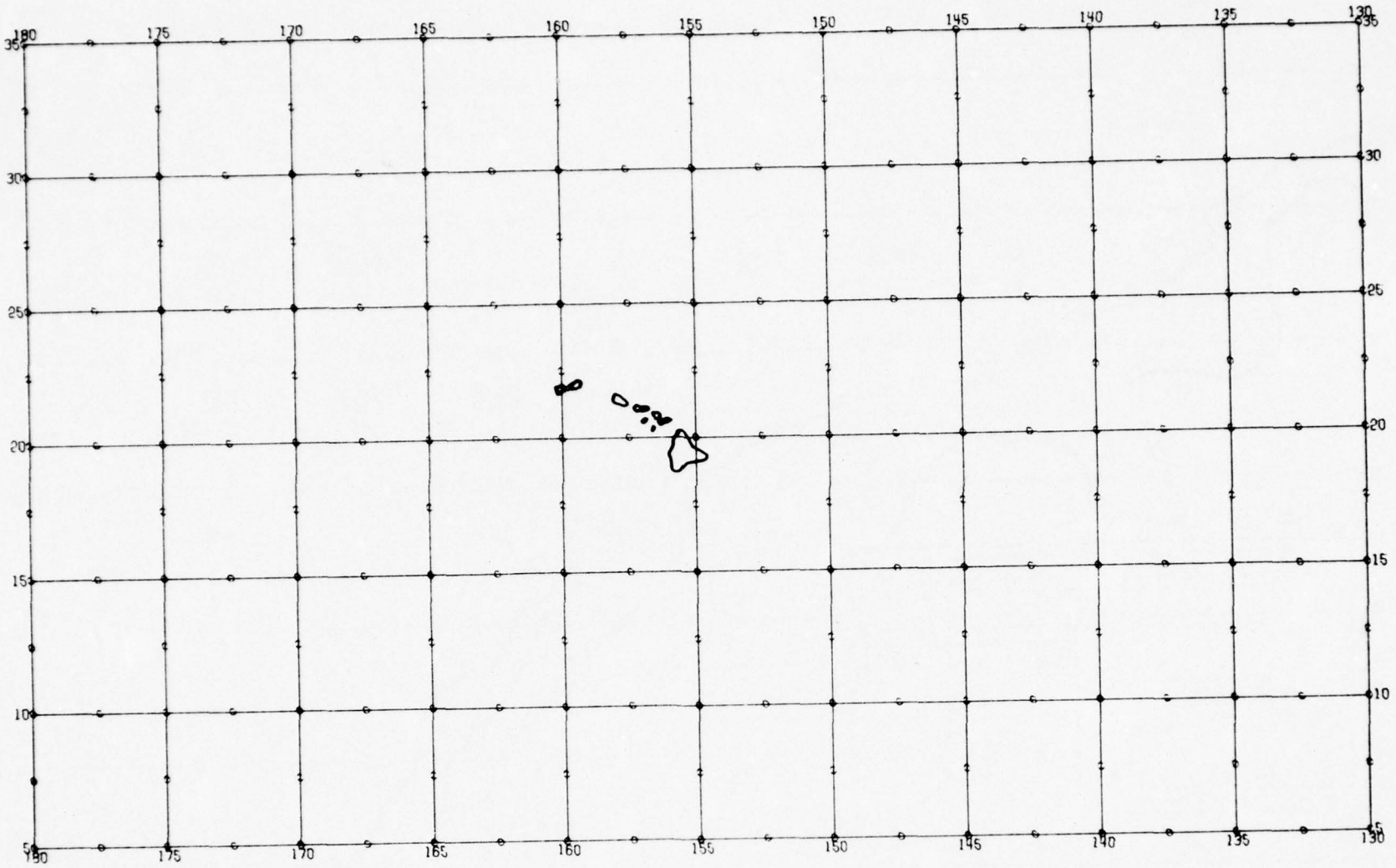


Figure 4-6a. Twelve-hour movement analysis, 16-30 June, western section. No tropical storms or hurricanes were documented during this period.

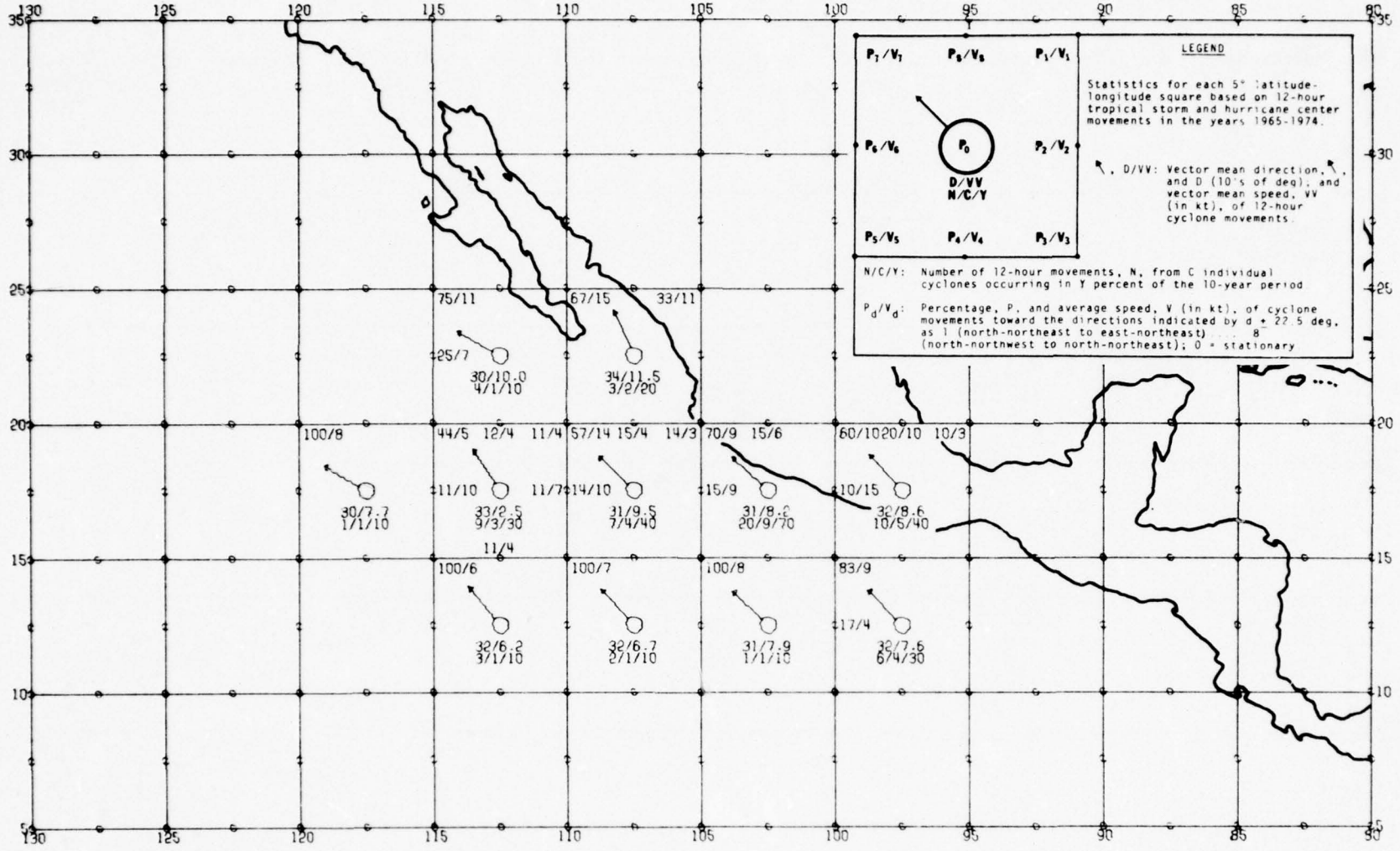


Figure 4-6b. Twelve-hour movement analysis, 16-30 June, eastern section.

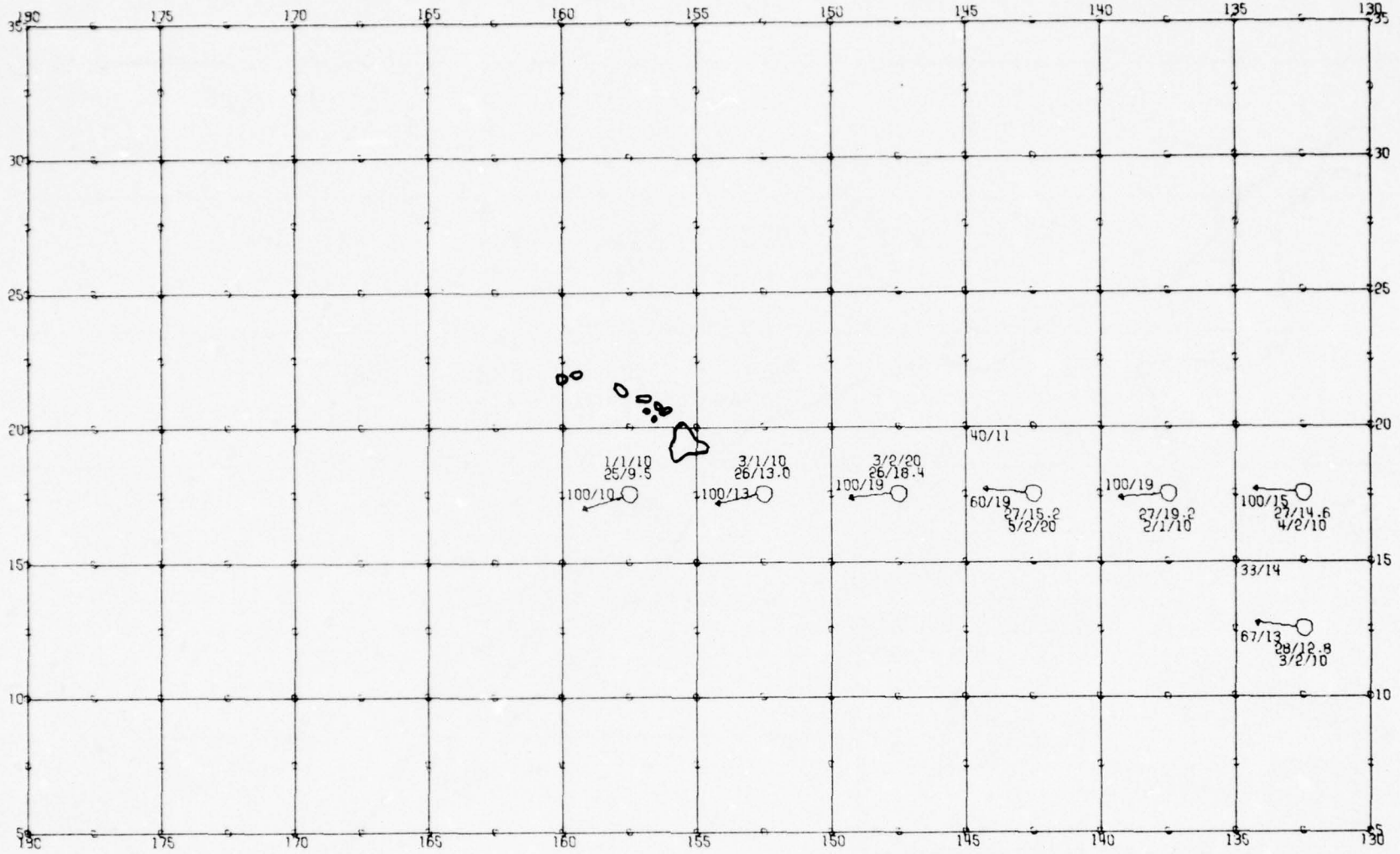


Figure 4-7a. Twelve-hour movement analysis, 1-15 July, western section.

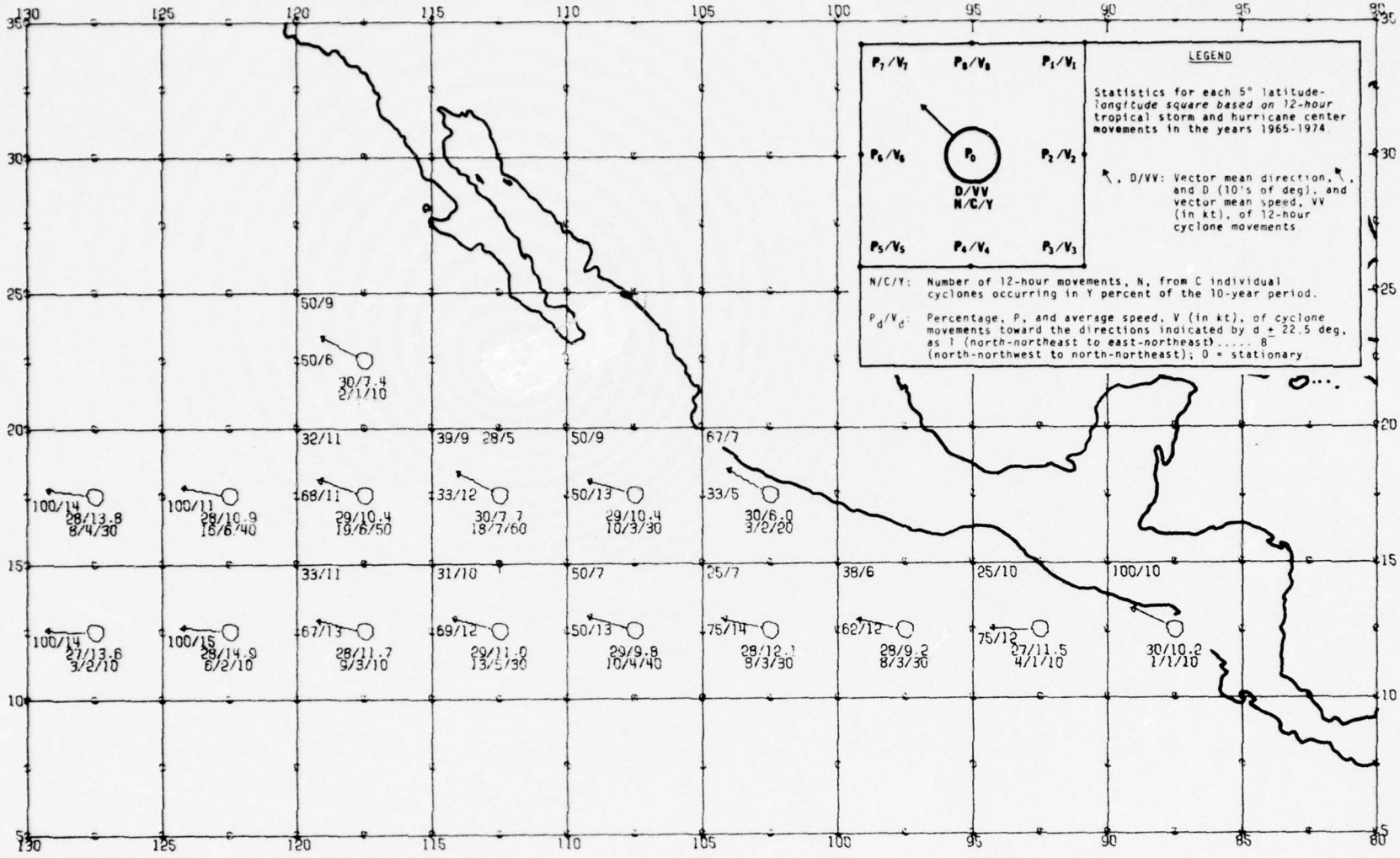


Figure 4-7b. Twelve-hour movement analysis, 1-15 July, eastern section.

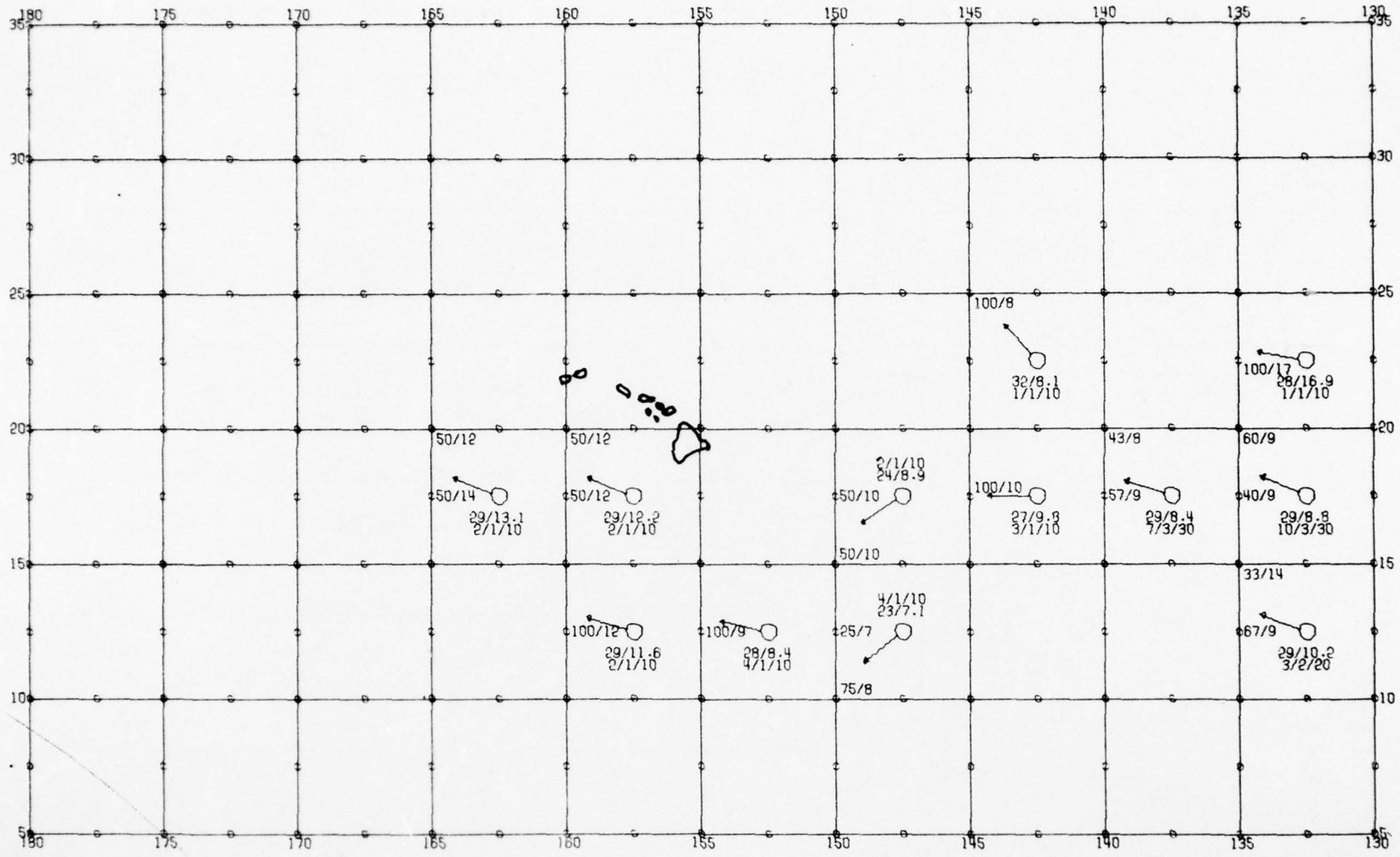


Figure 4-8a. Twelve-hour movement analysis, 16-31 July, western section.

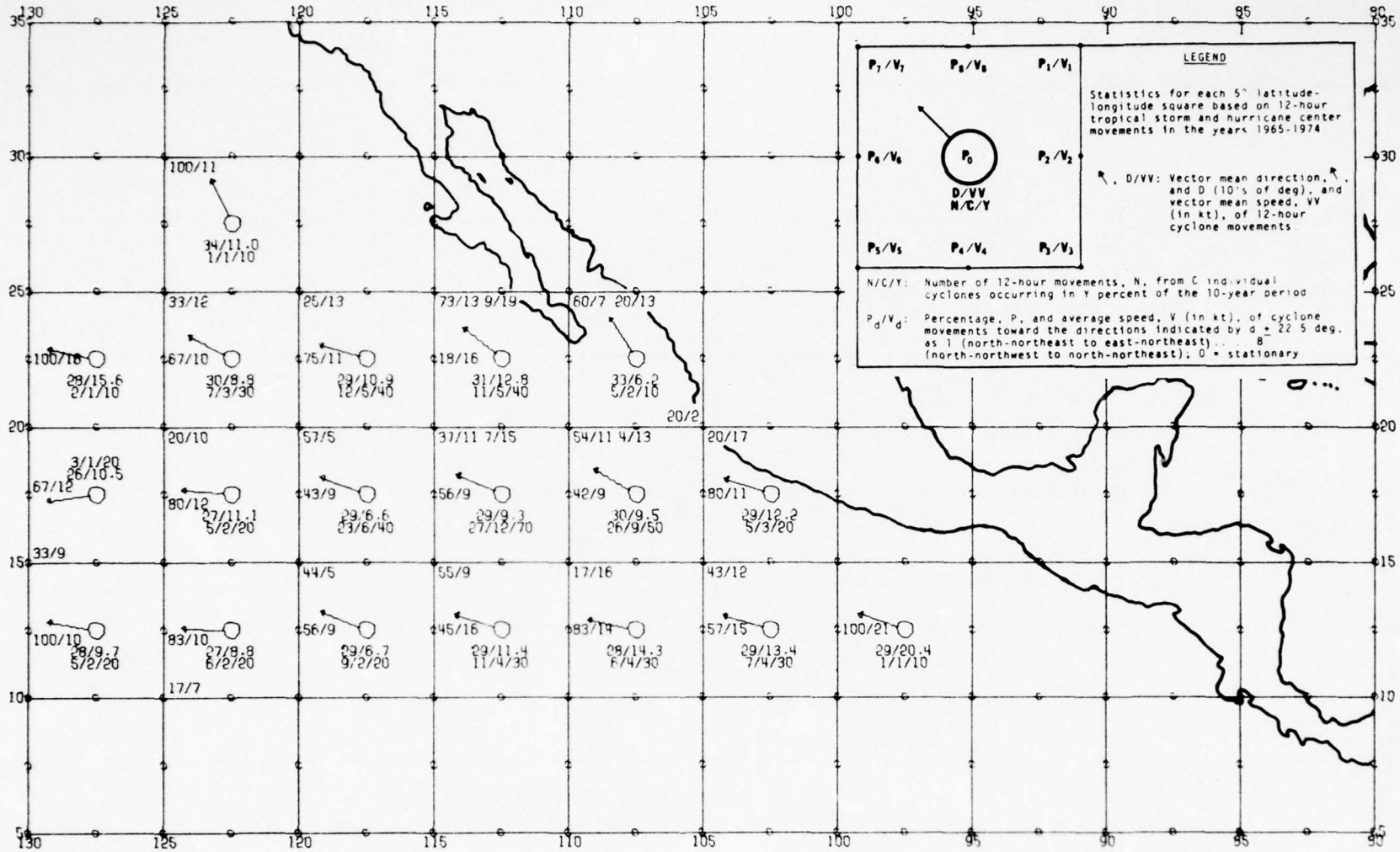


Figure 4-8b. Twelve-hour movement analysis, 16-31 July, eastern section.

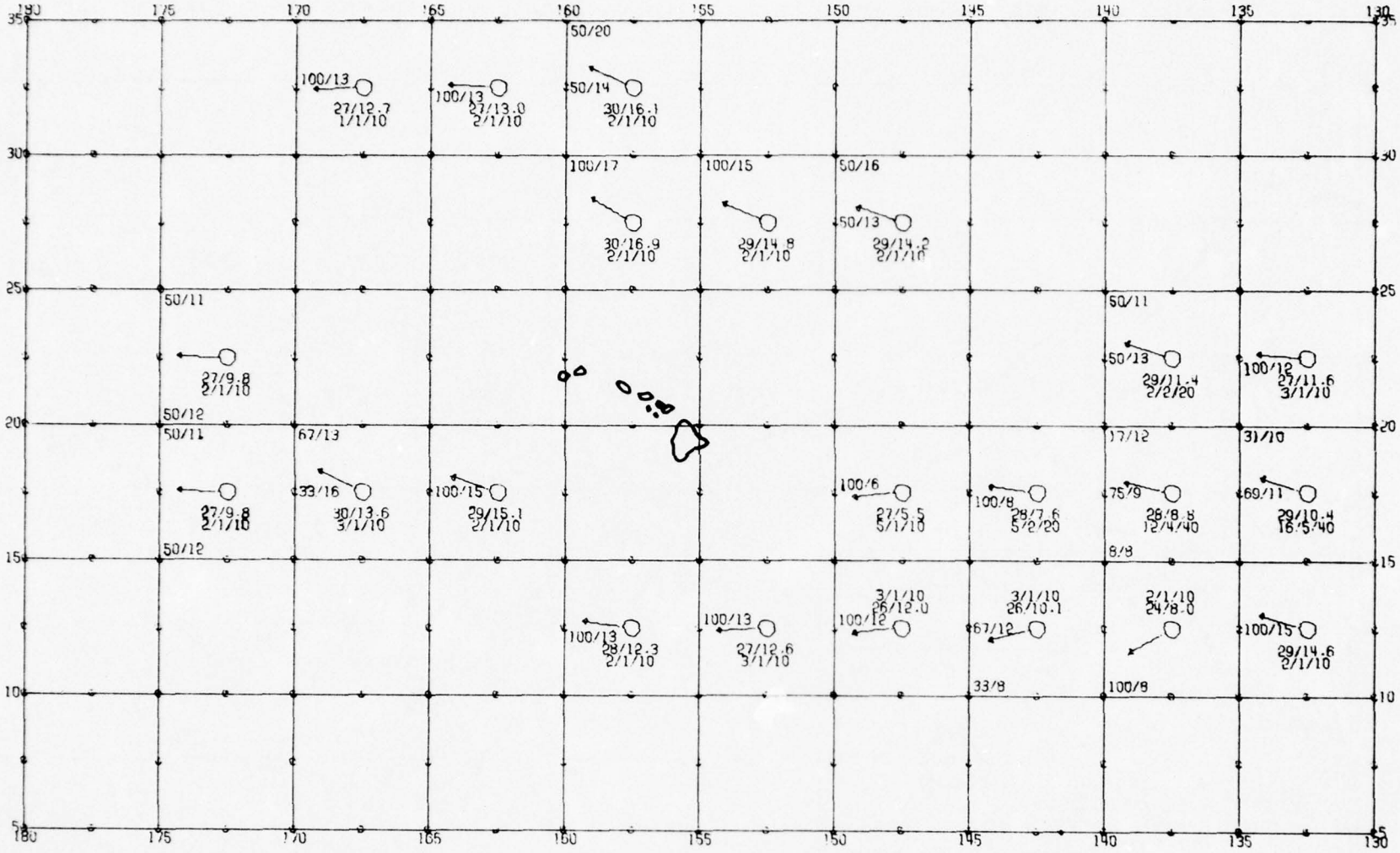


Figure 4-9a. Twelve-hour movement analysis, 1-15 August, western section.

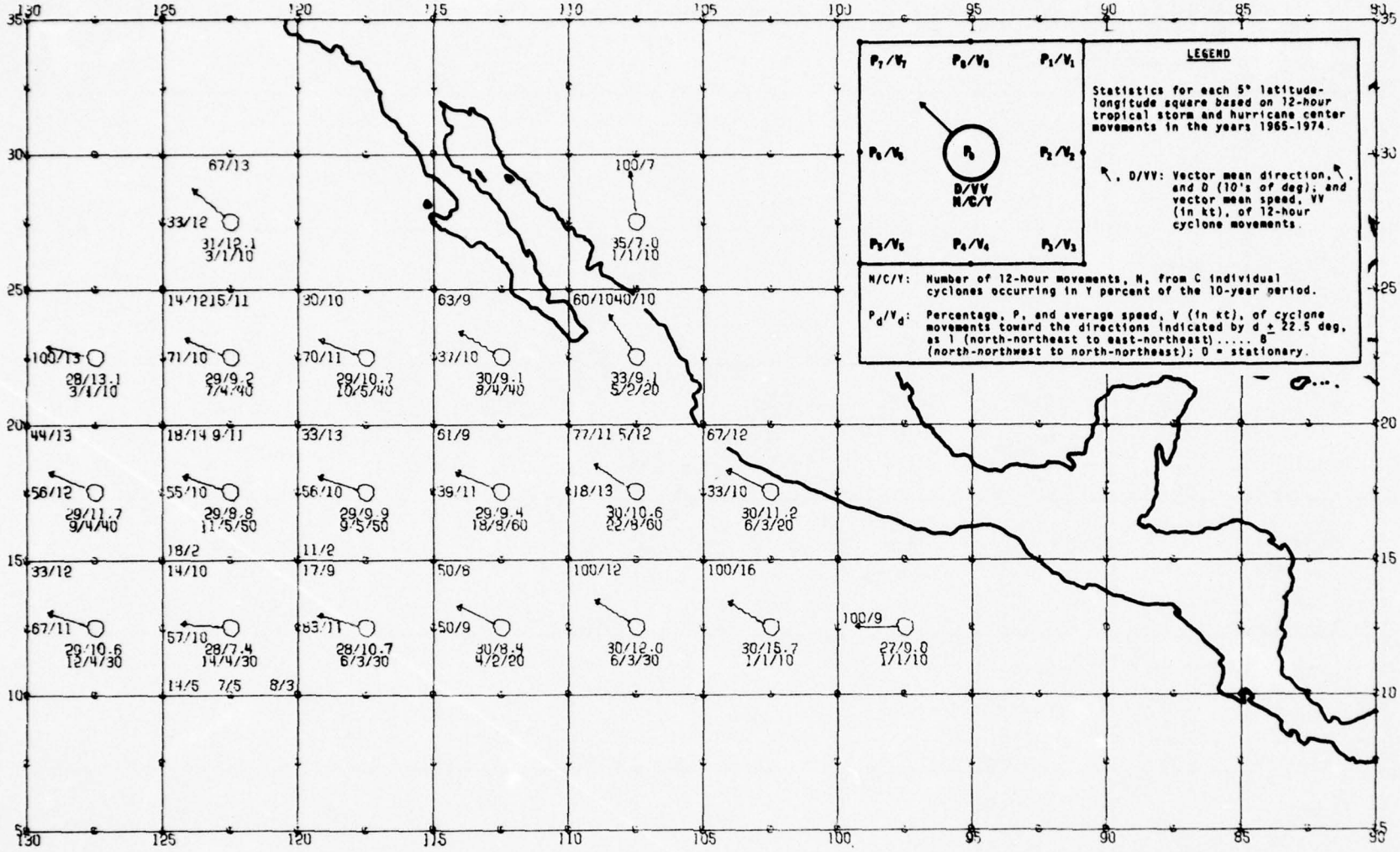


Figure 4-9b. Twelve-hour movement analysis, 1-15 August, eastern section.

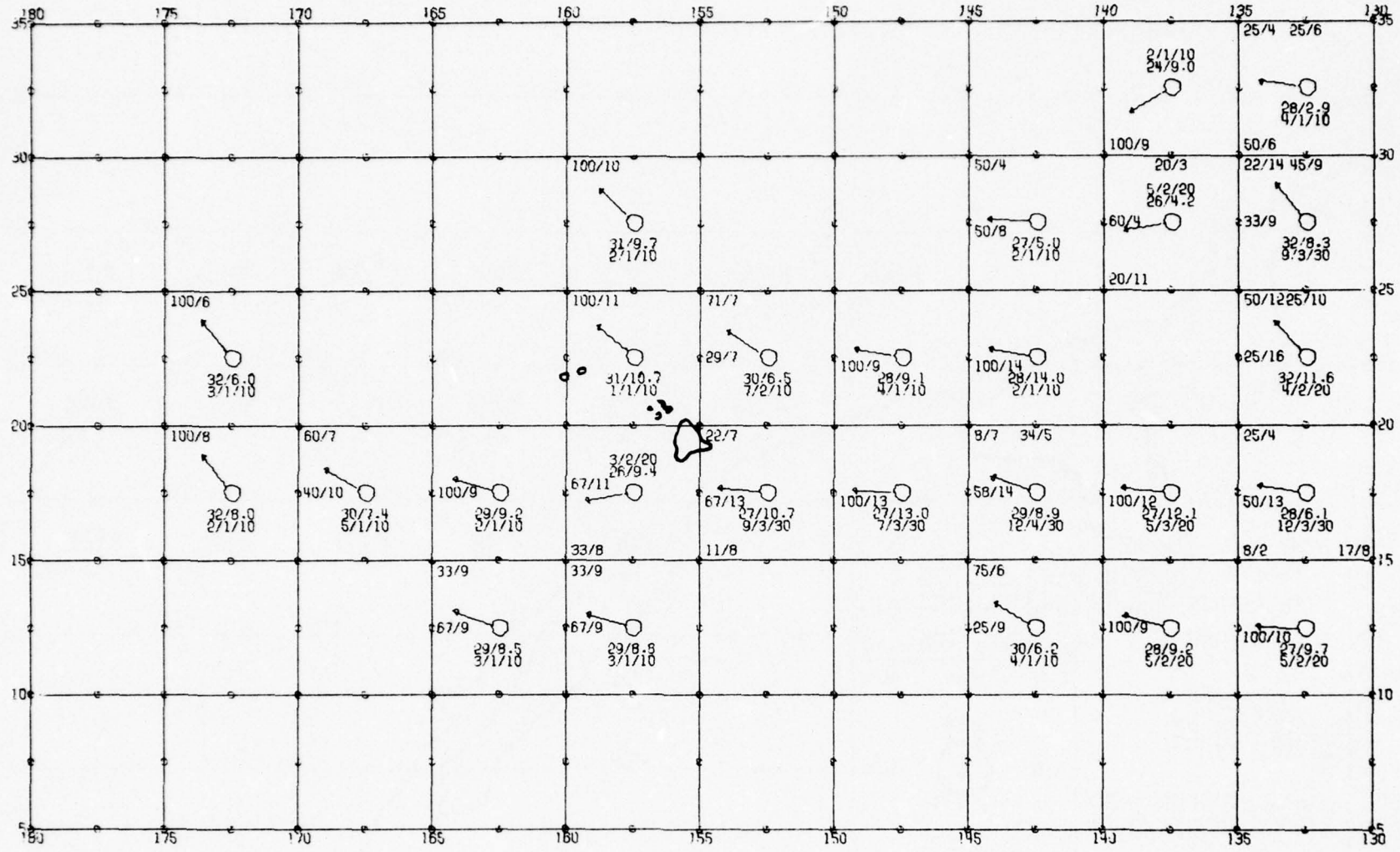


Figure 4-10a. Twelve-hour movement analysis, 16-31 August, western section.

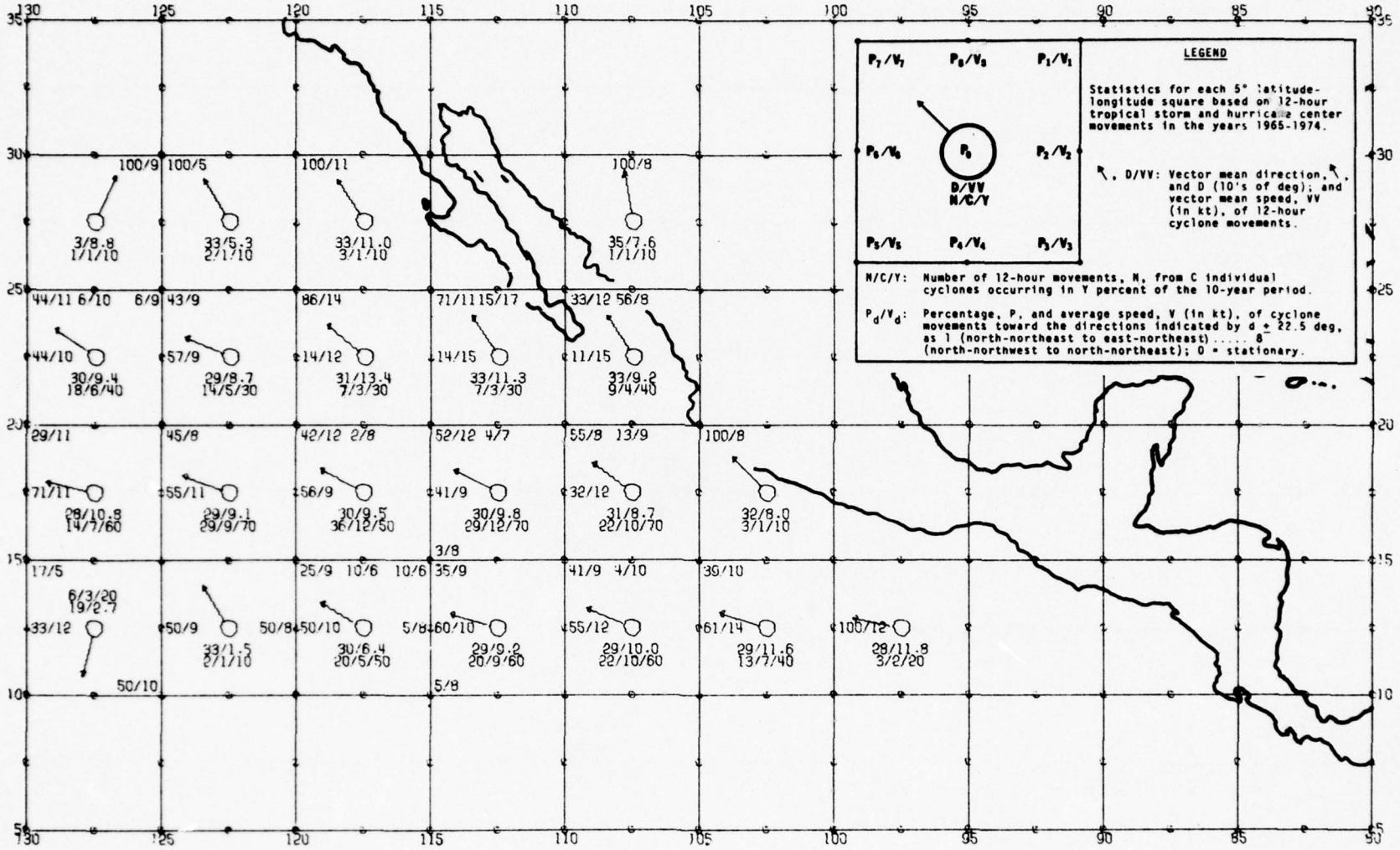


Figure 4-10b. Twelve-hour movement analysis, 16-31 August, eastern section.

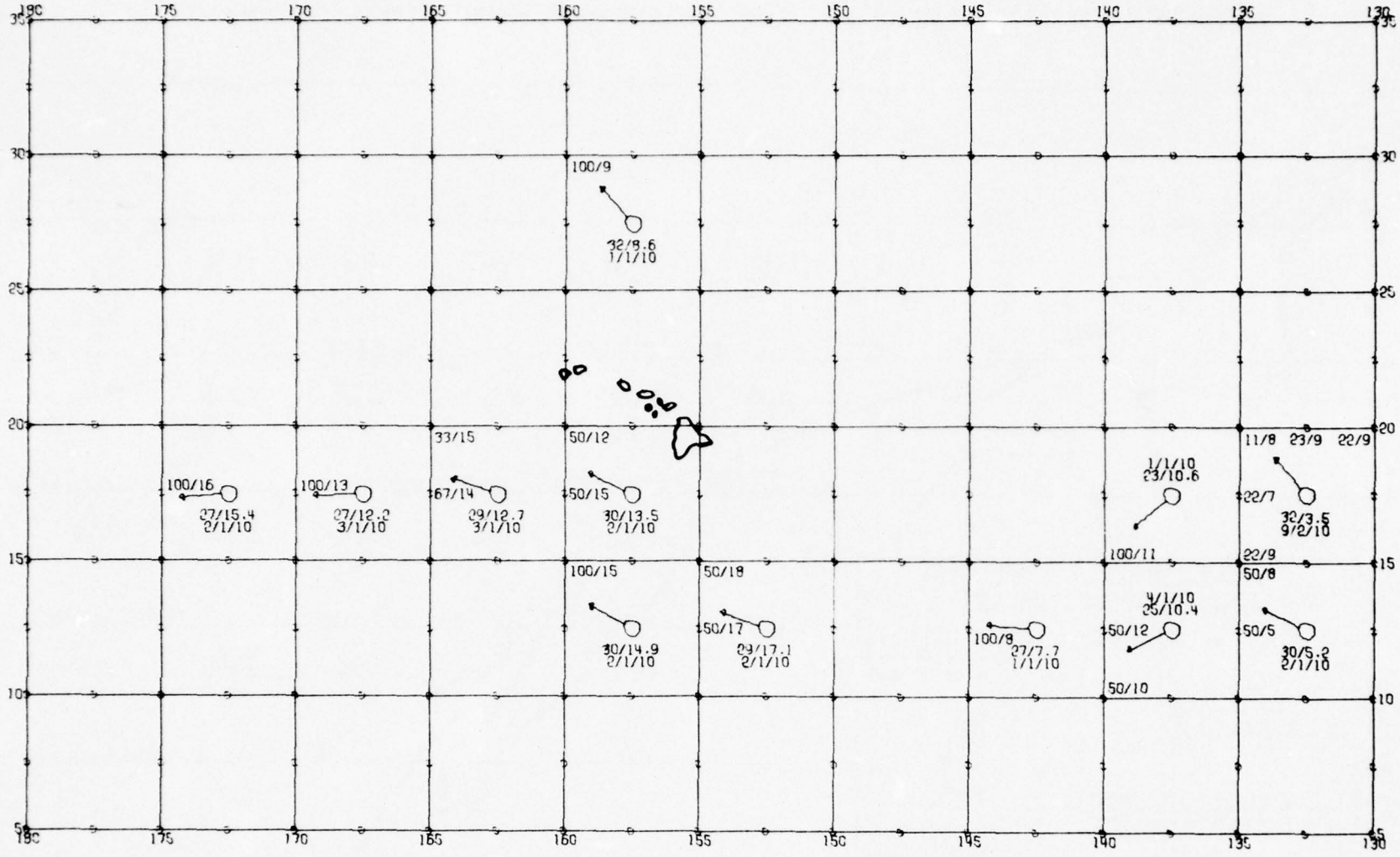


Figure 4-11a. Twelve-hour movement analysis, 1-15 September, western section.

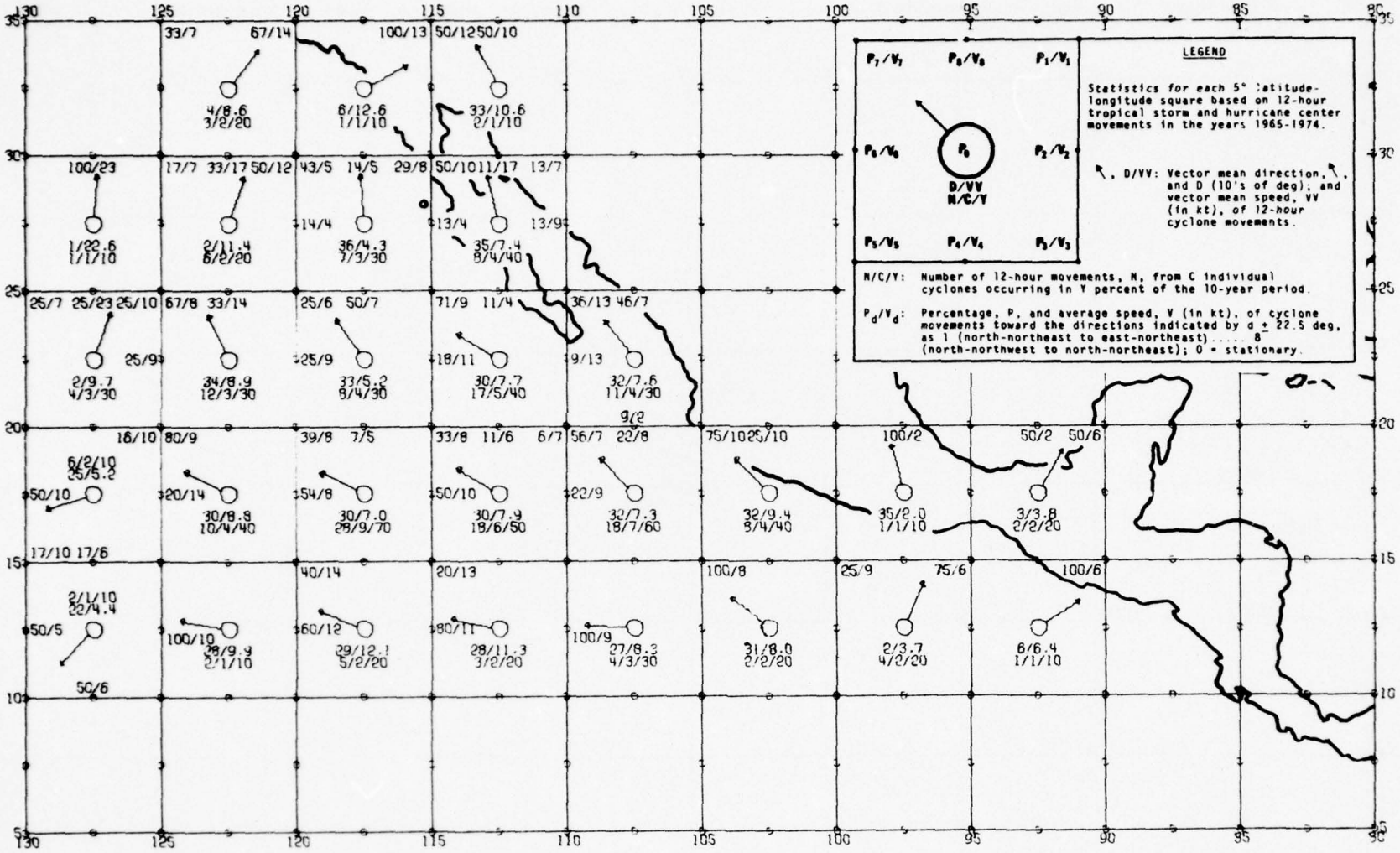


Figure 4-11b. Twelve-hour movement analysis, 1-15 September, eastern section.

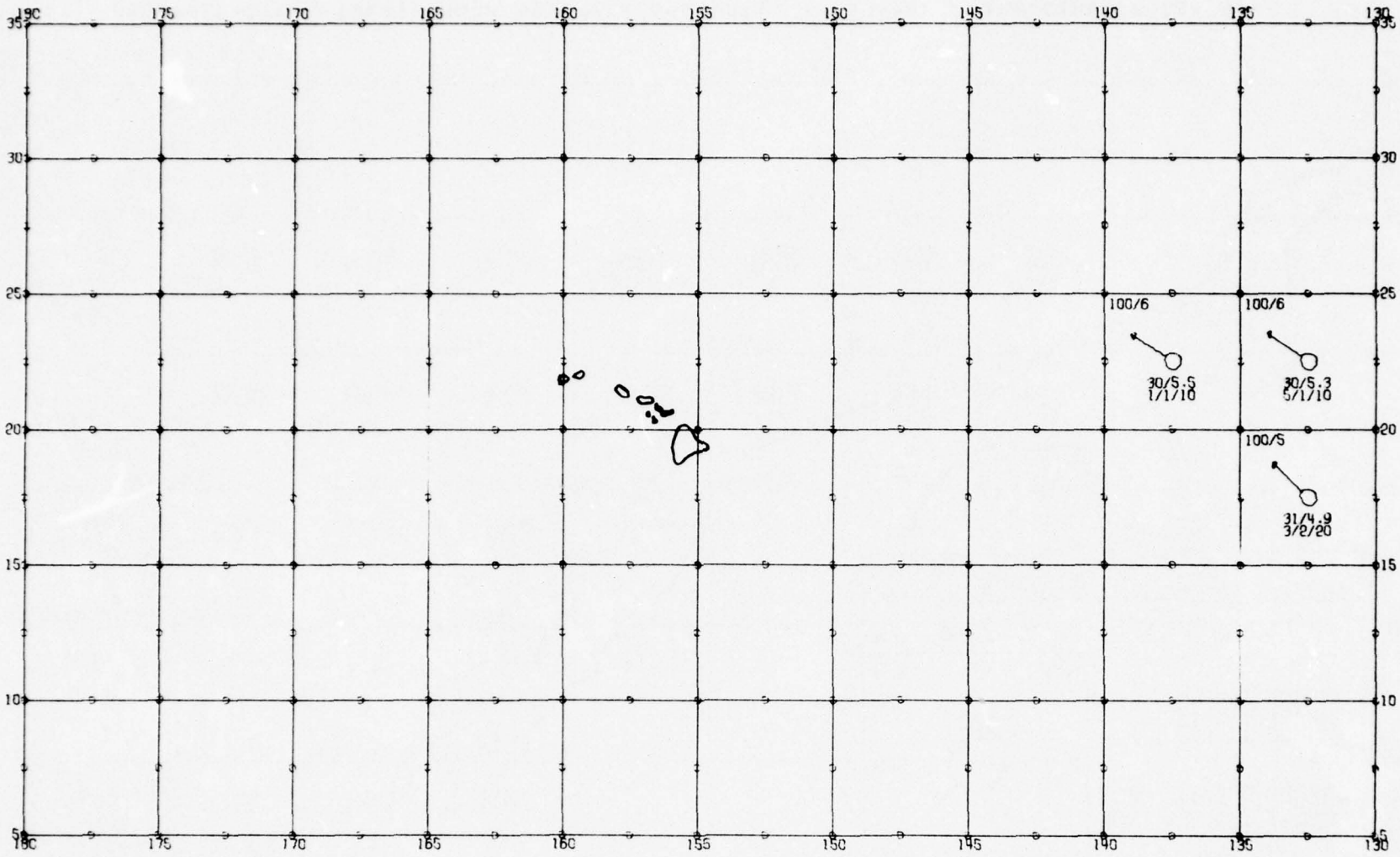


Figure 4-12a. Twelve-hour movement analysis, 16-30 September, western section.

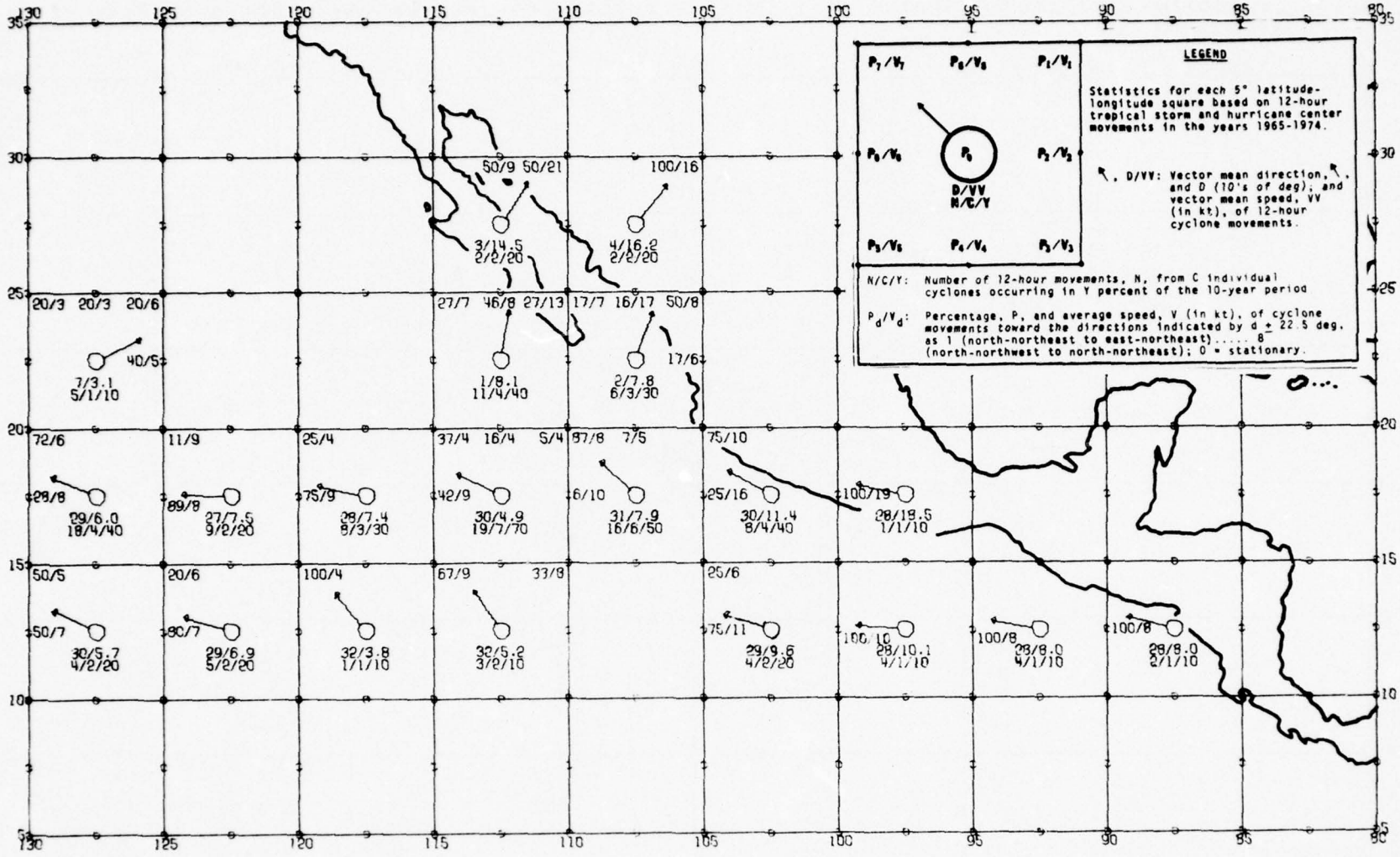


Figure 4-12b. Twelve-hour movement analysis, 16-30 September, eastern section.

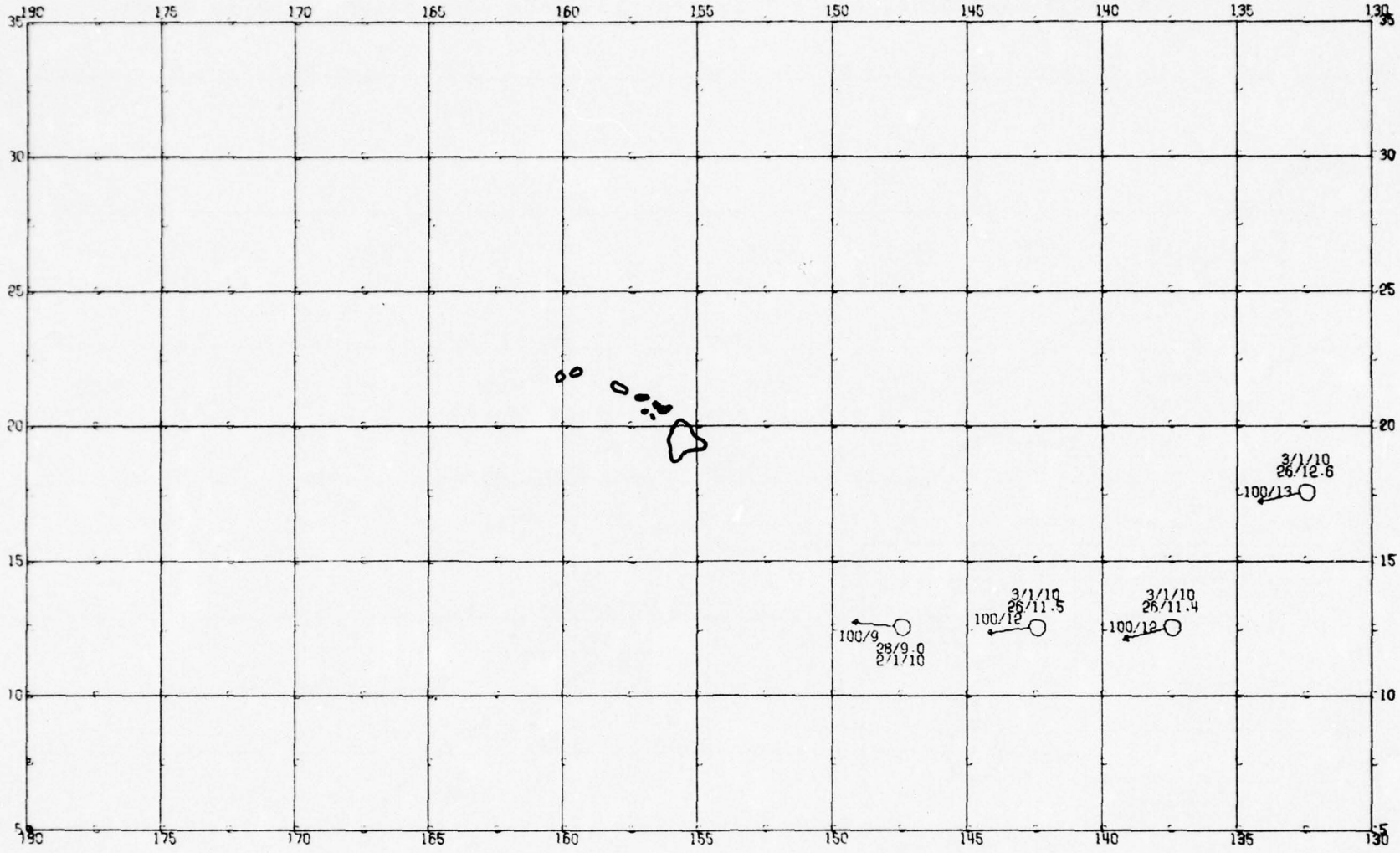


Figure 4-13a. Twelve-hour movement analysis, 1-15 October, western section.

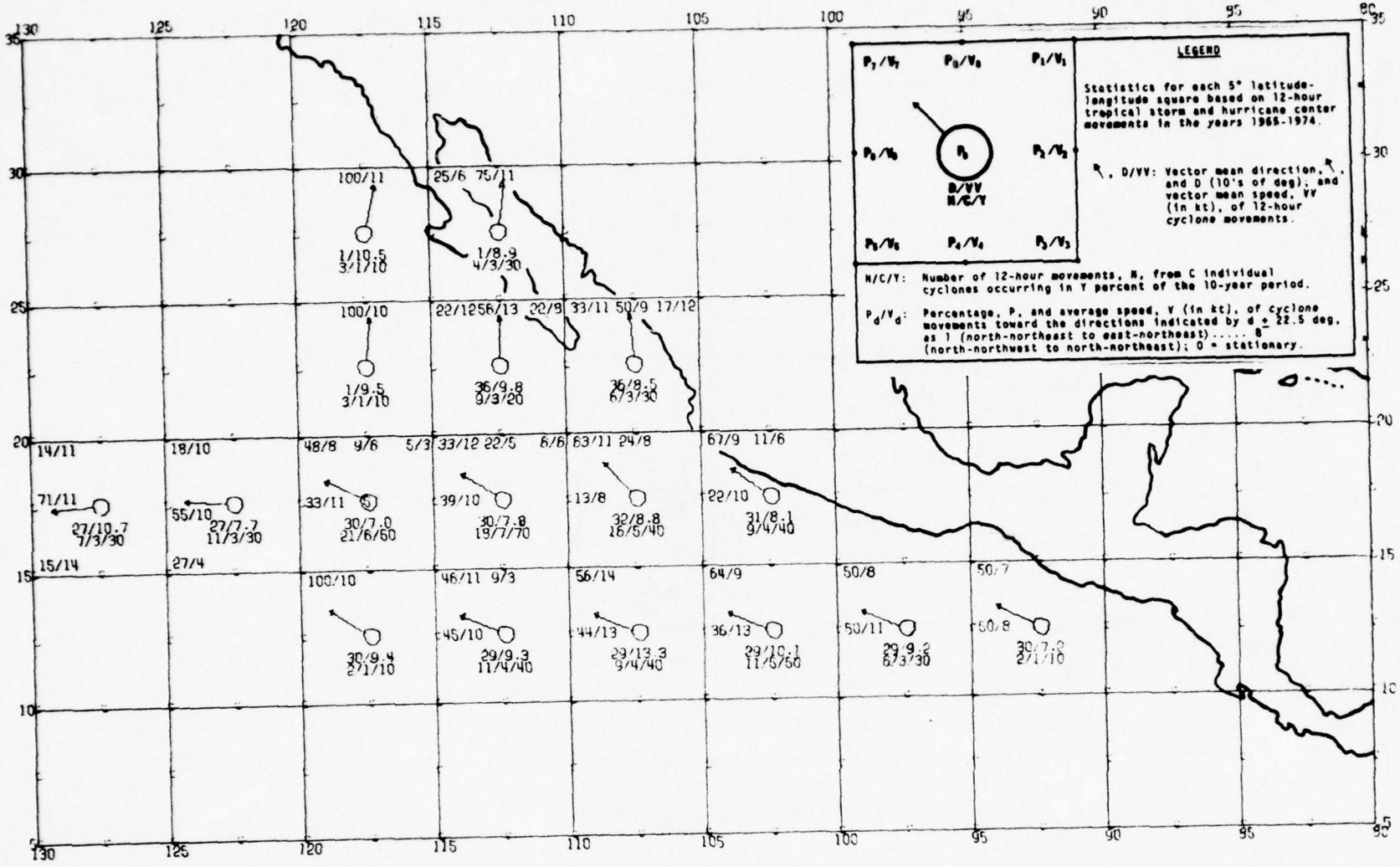


Figure 4-13b. Twelve-hour movement analysis, 1-15 October, eastern section.

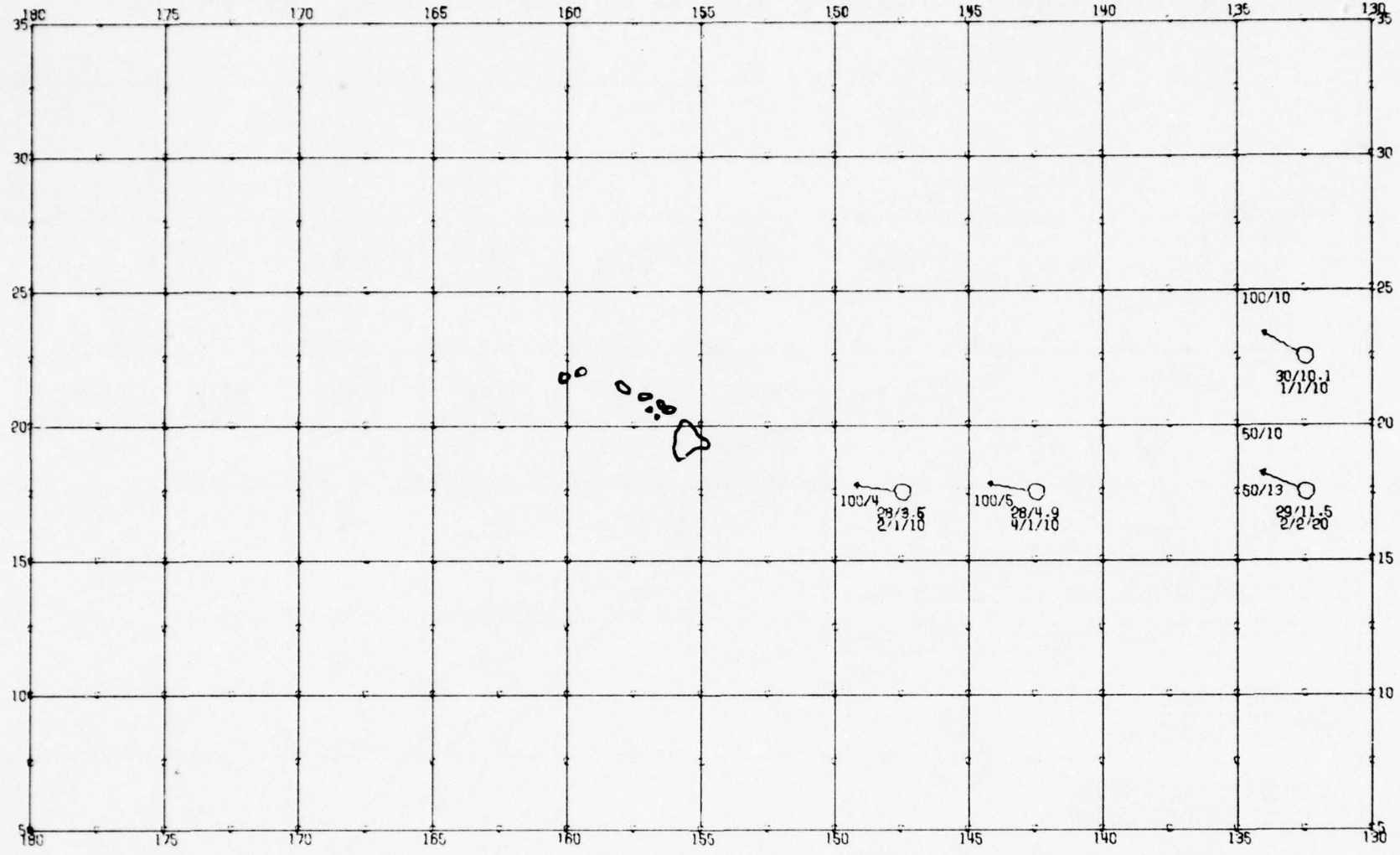


Figure 4-14a. Twelve-hour movement analysis, 16-31 October, western section.

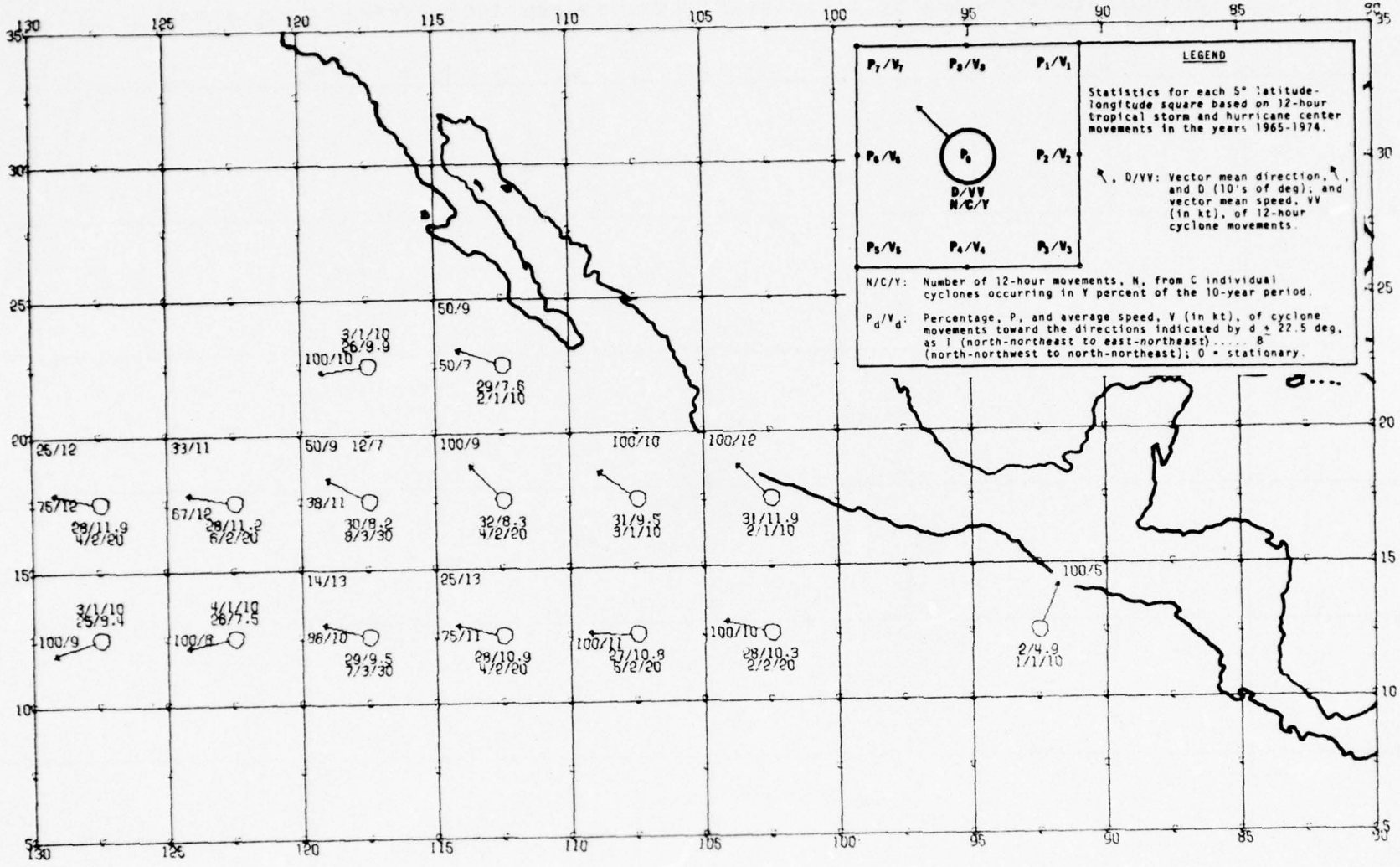


Figure 4-14b. Twelve-hour movement analysis, 16-31 October, eastern section.

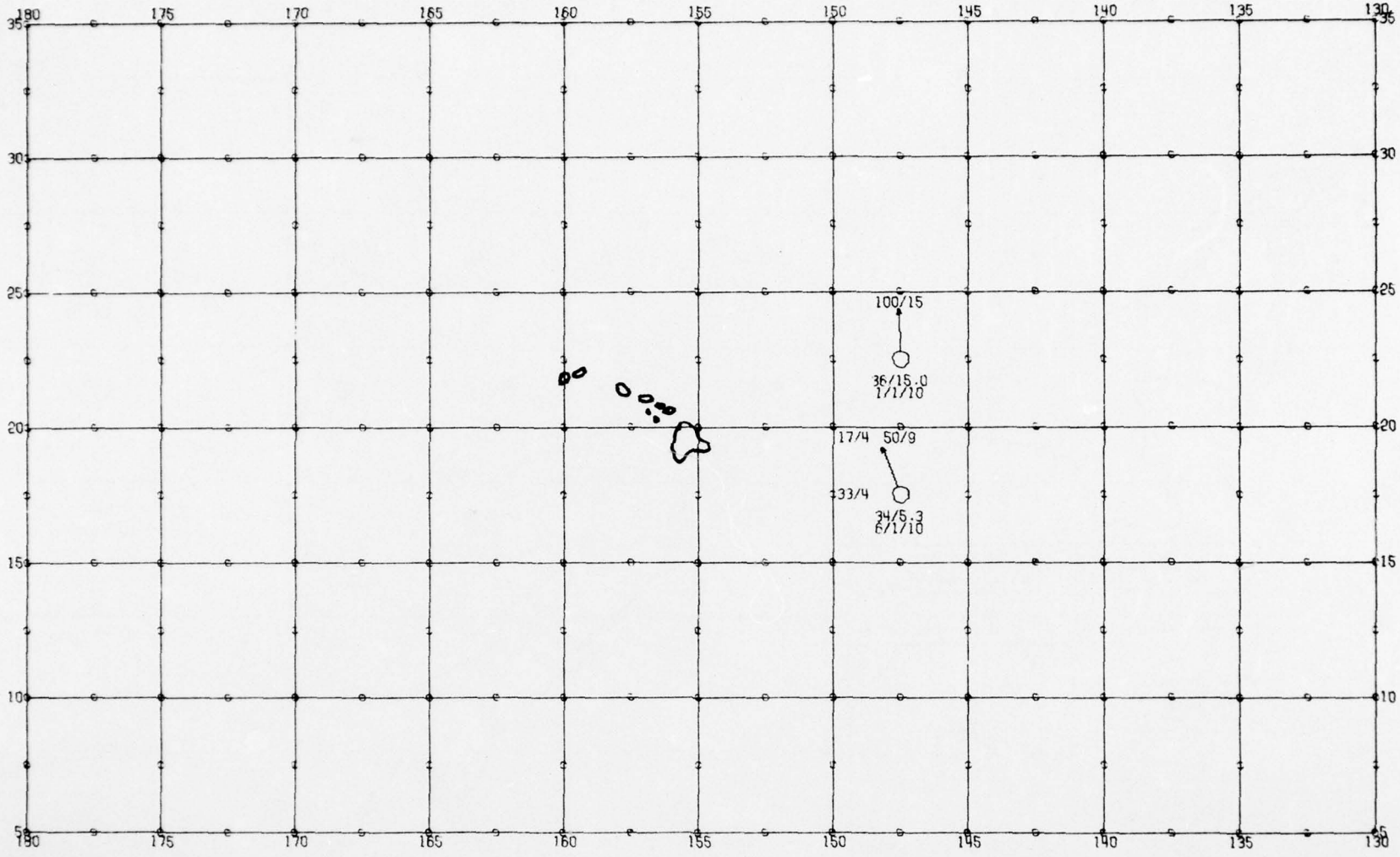


Figure 4-15a. Twelve-hour movement analysis, 1-15 November, western section.

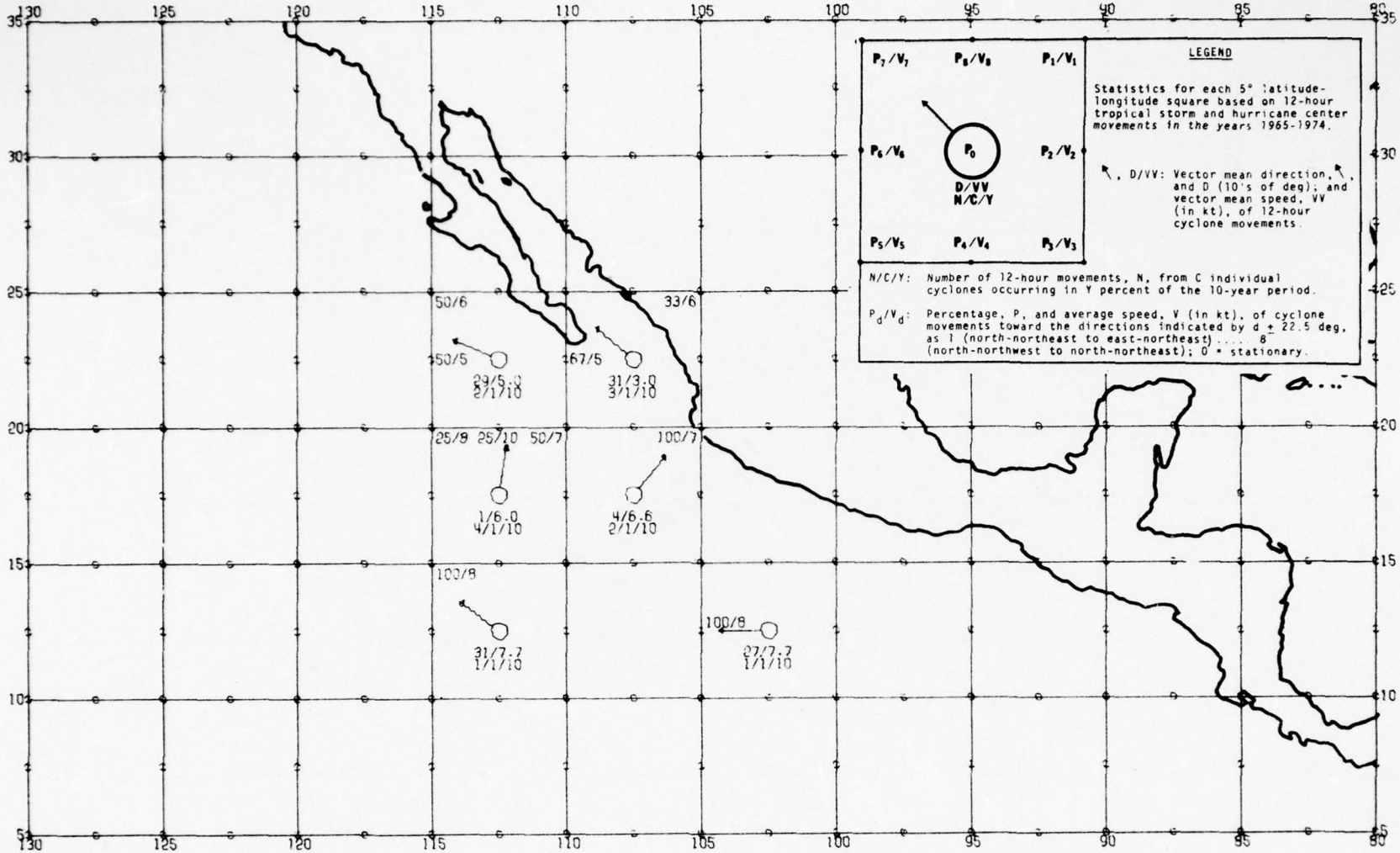


Figure 4-15b. Twelve-hour movement analysis, 1-15 November, eastern section.

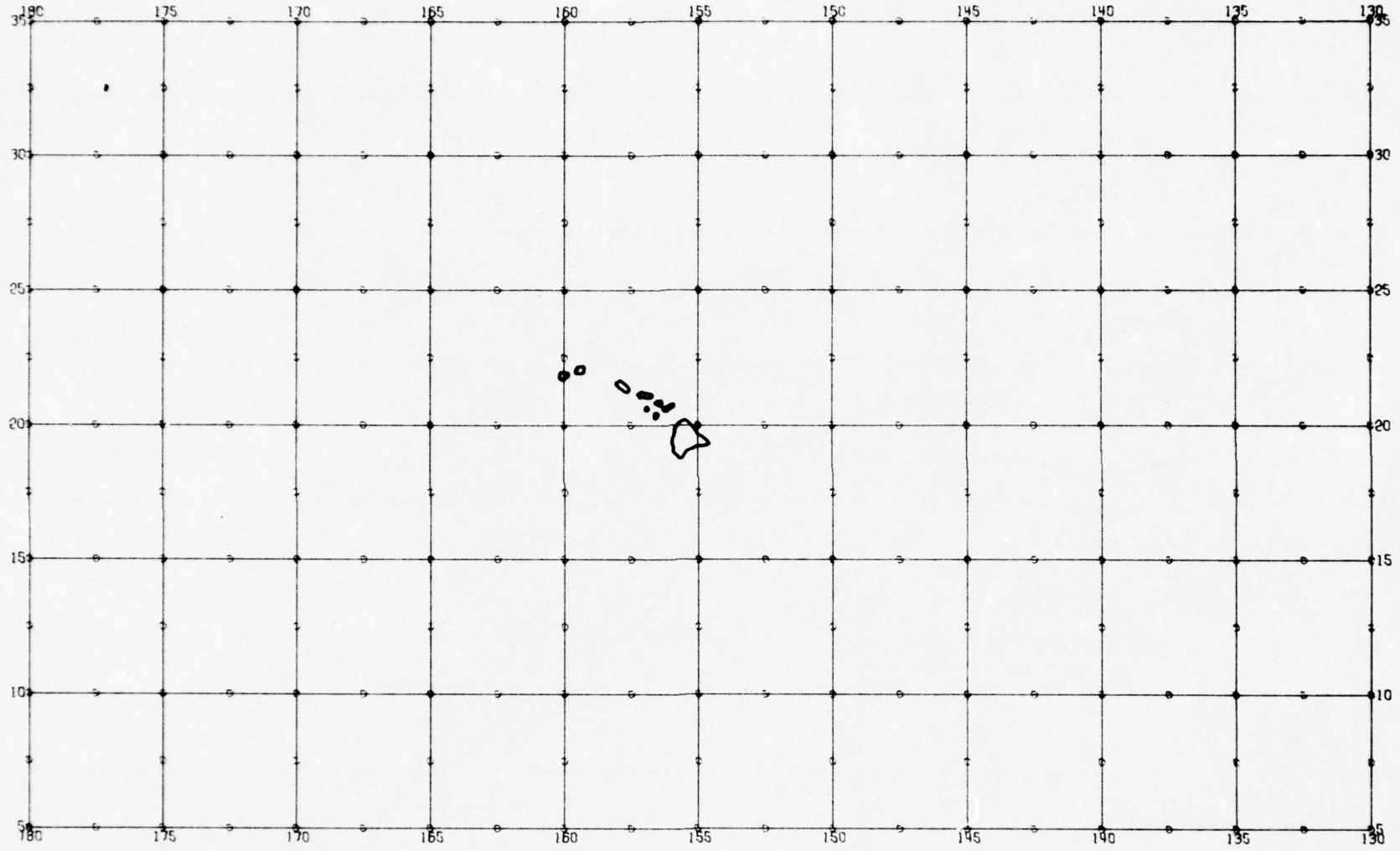


Figure 4-16a. Twelve-hour movement analysis, May, western section. No tropical storms or hurricanes were documented during this period.

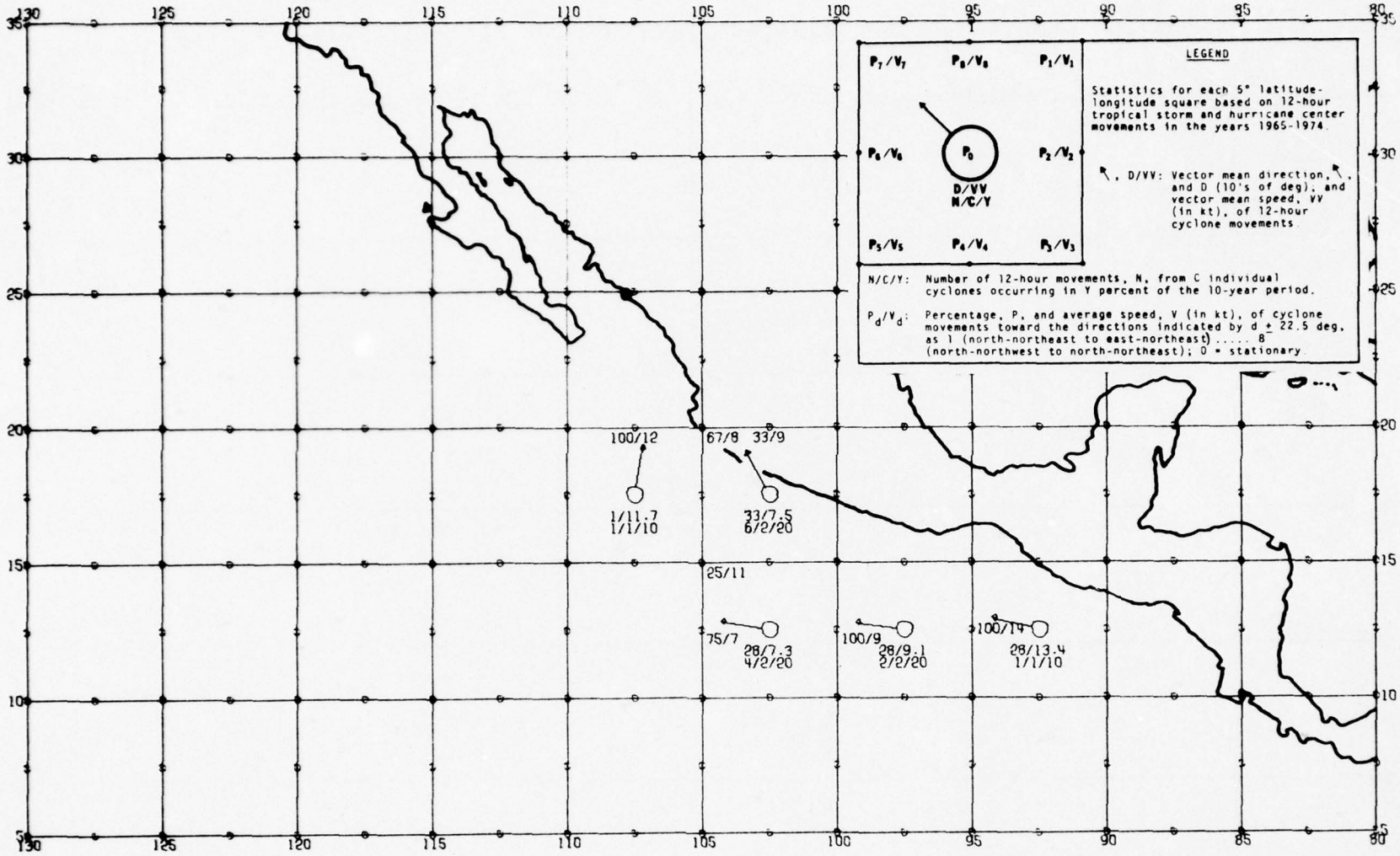


Figure 4-16b. Twelve-hour movement analysis, May, eastern section.

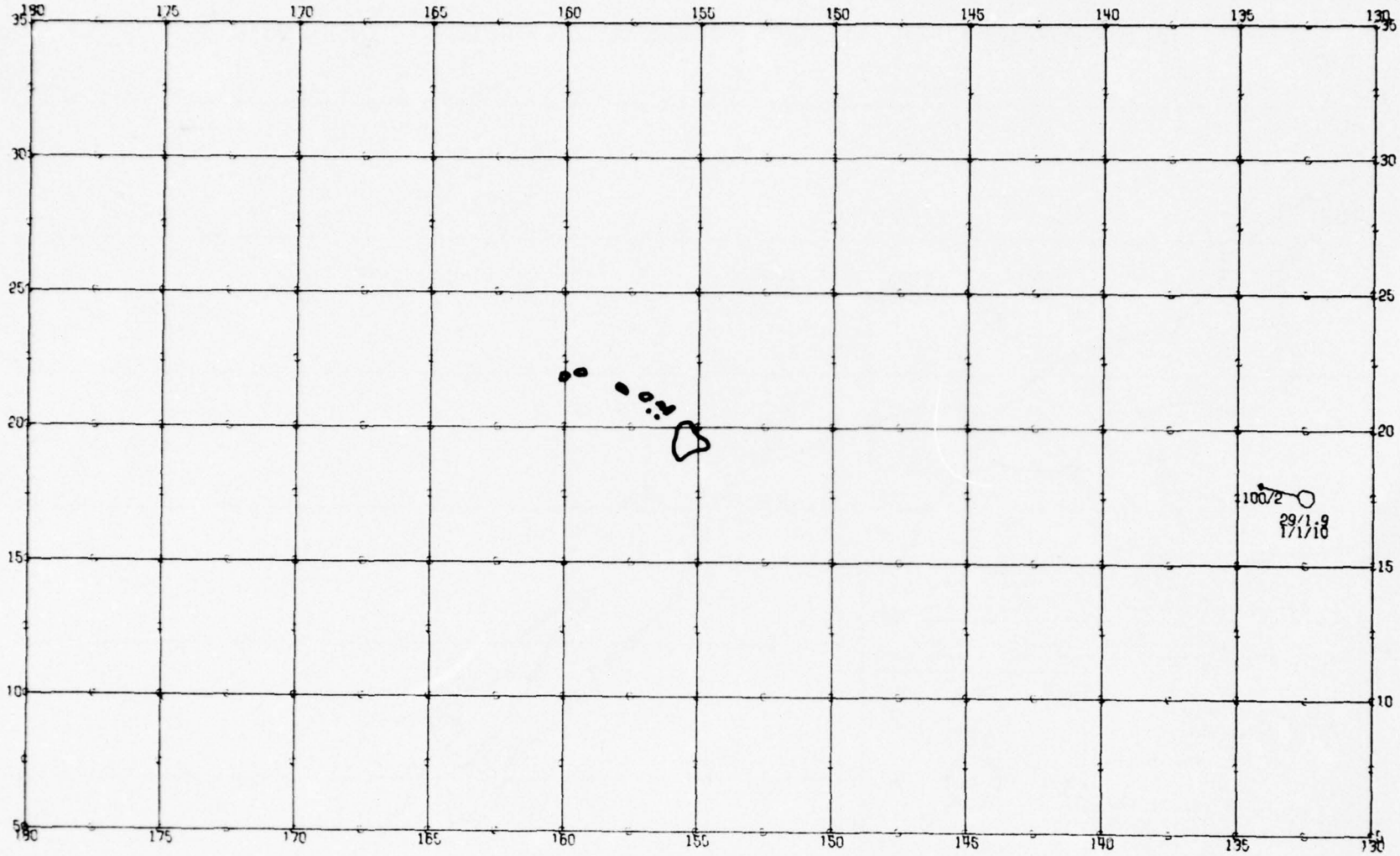


Figure 4-17a. Twelve-hour movement analysis, June, western section.

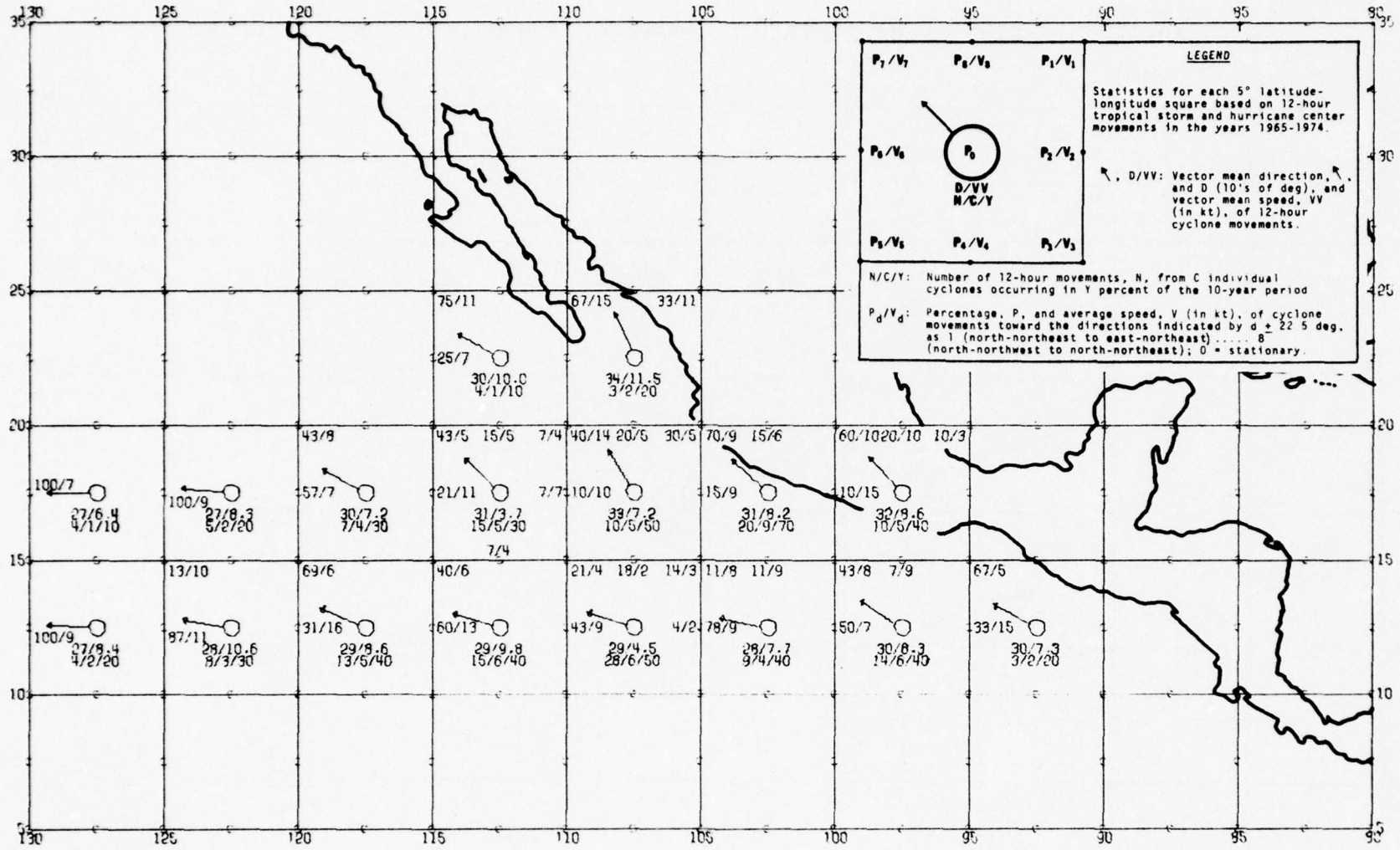


Figure 4-17b. Twelve-hour movement analysis, June, eastern section.

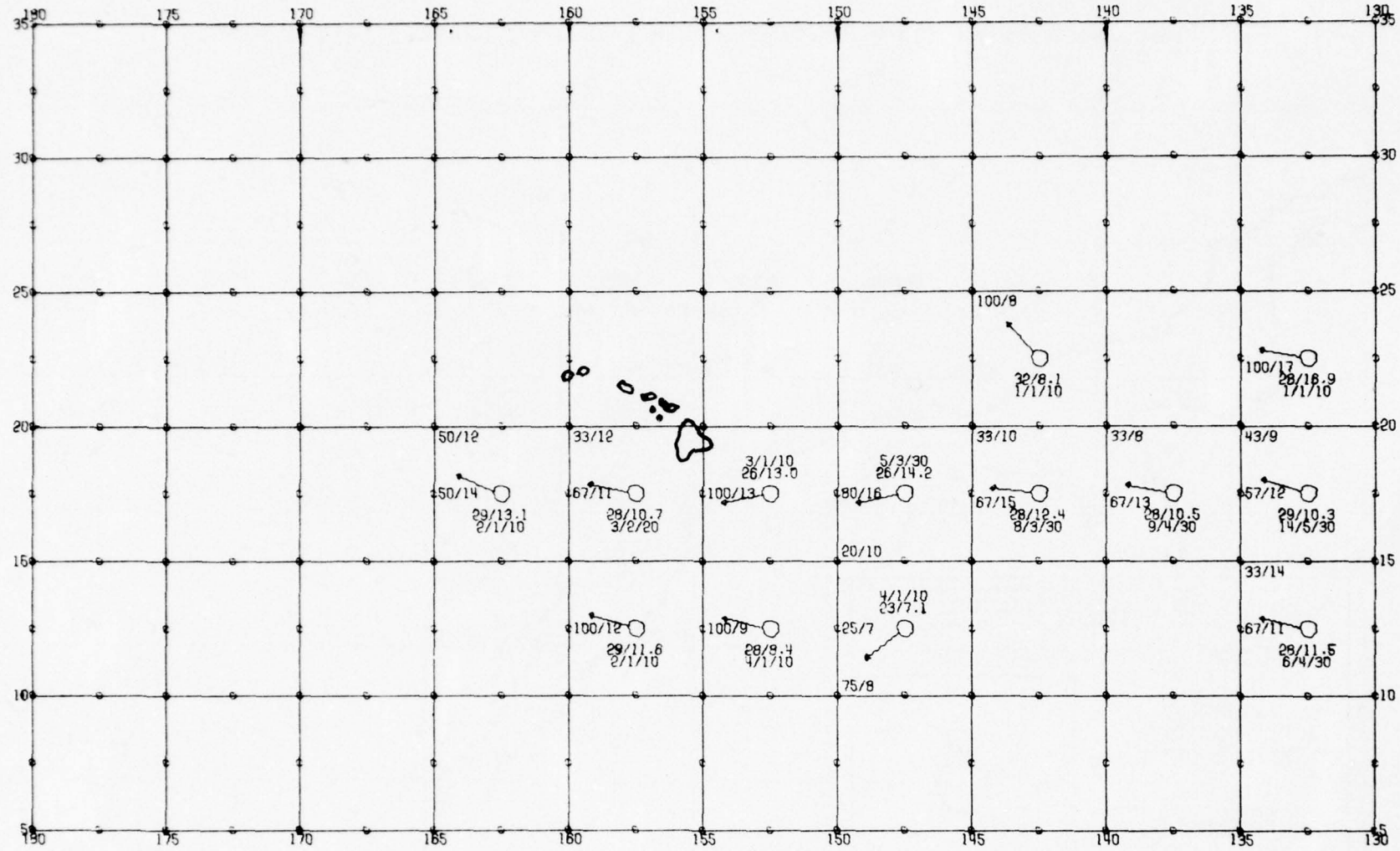


Figure 4-18a. Twelve-hour movement analysis, July, western section.

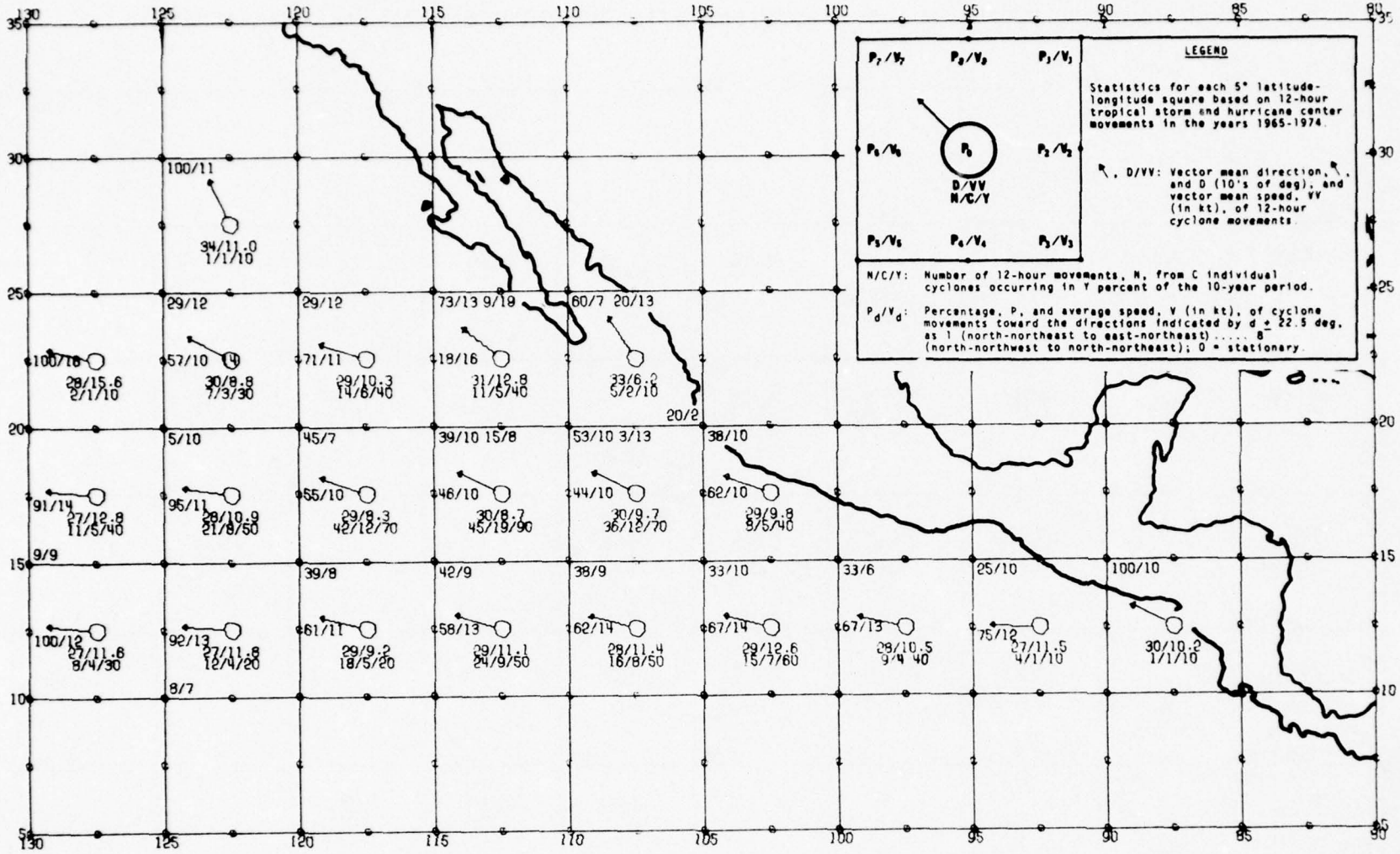


Figure 4-18b. Twelve-hour movement analysis, July, eastern section.

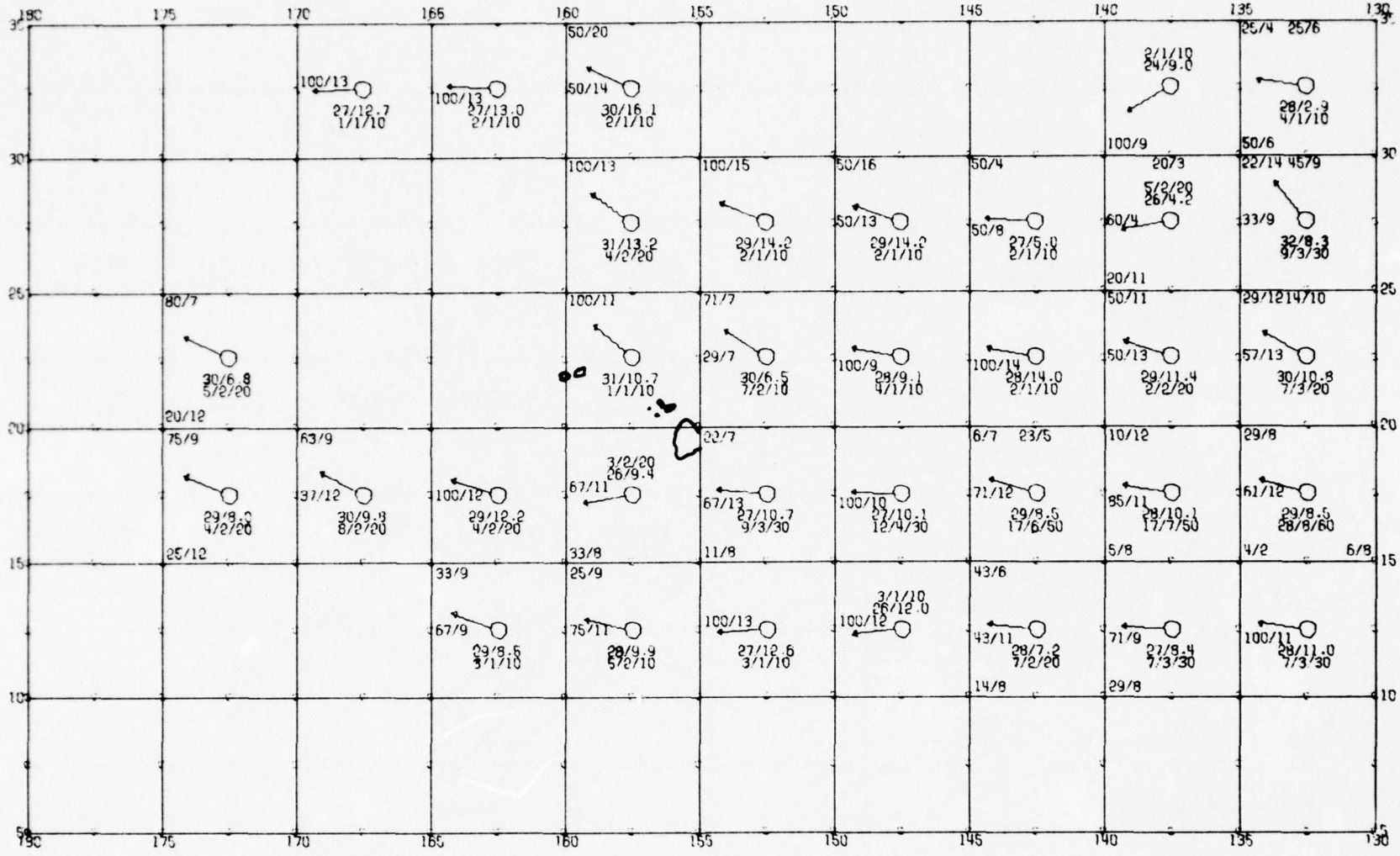


Figure 4-19a. Twelve-hour movement analysis, August, western section.

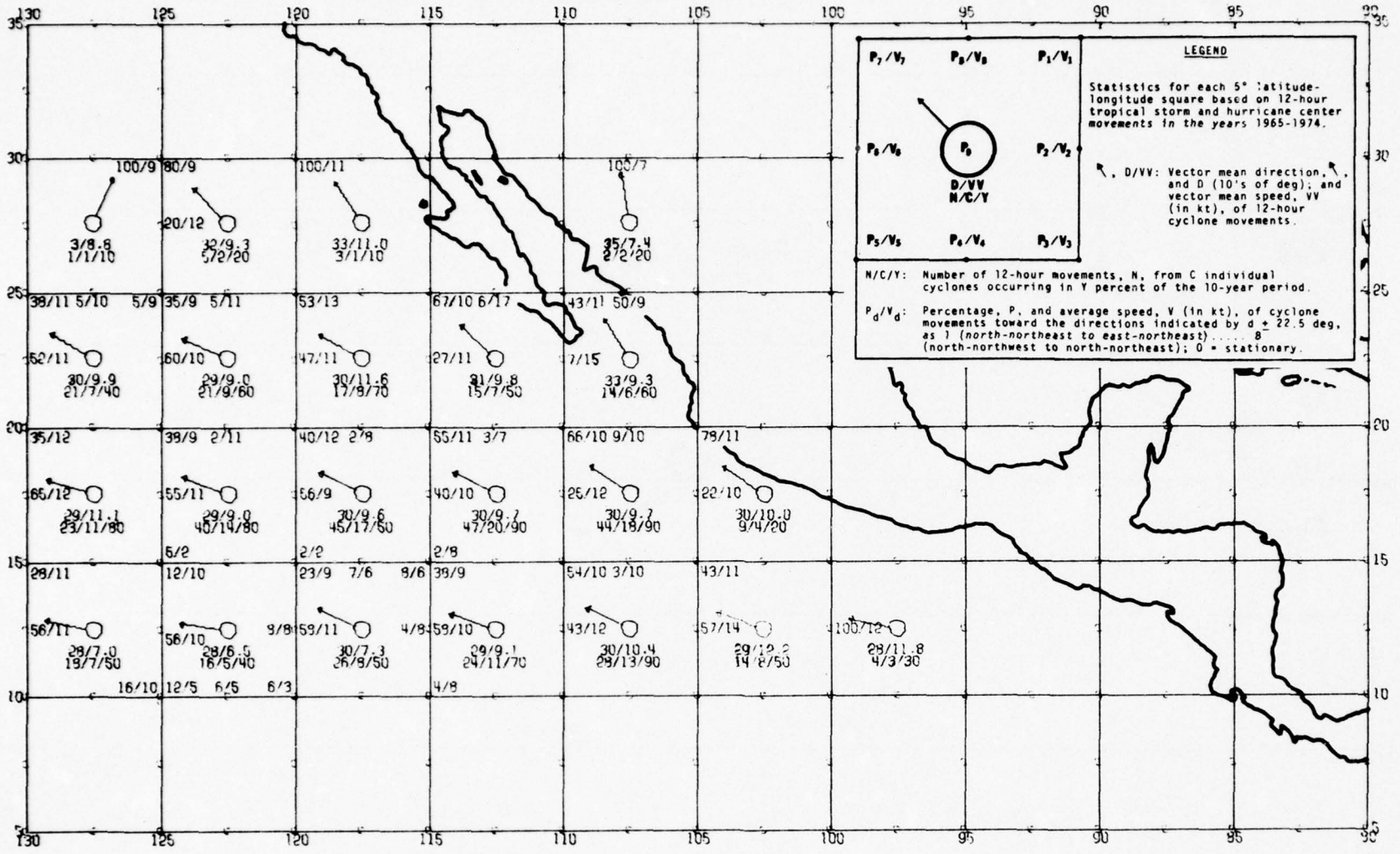


Figure 4-19b. Twelve-hour movement analysis, August, eastern section.

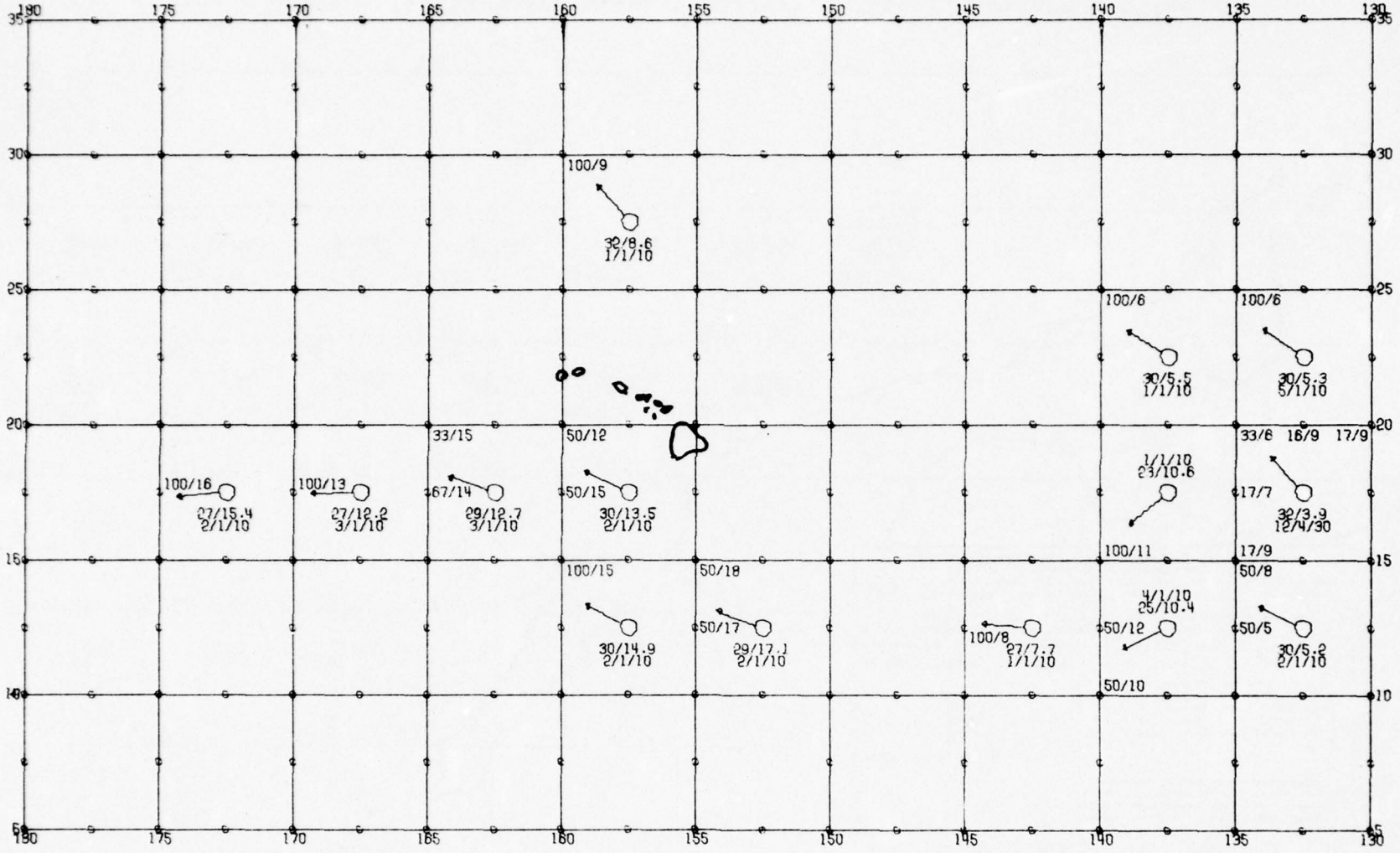


Figure 4-20a. Twelve-hour movement analysis, September, western section.

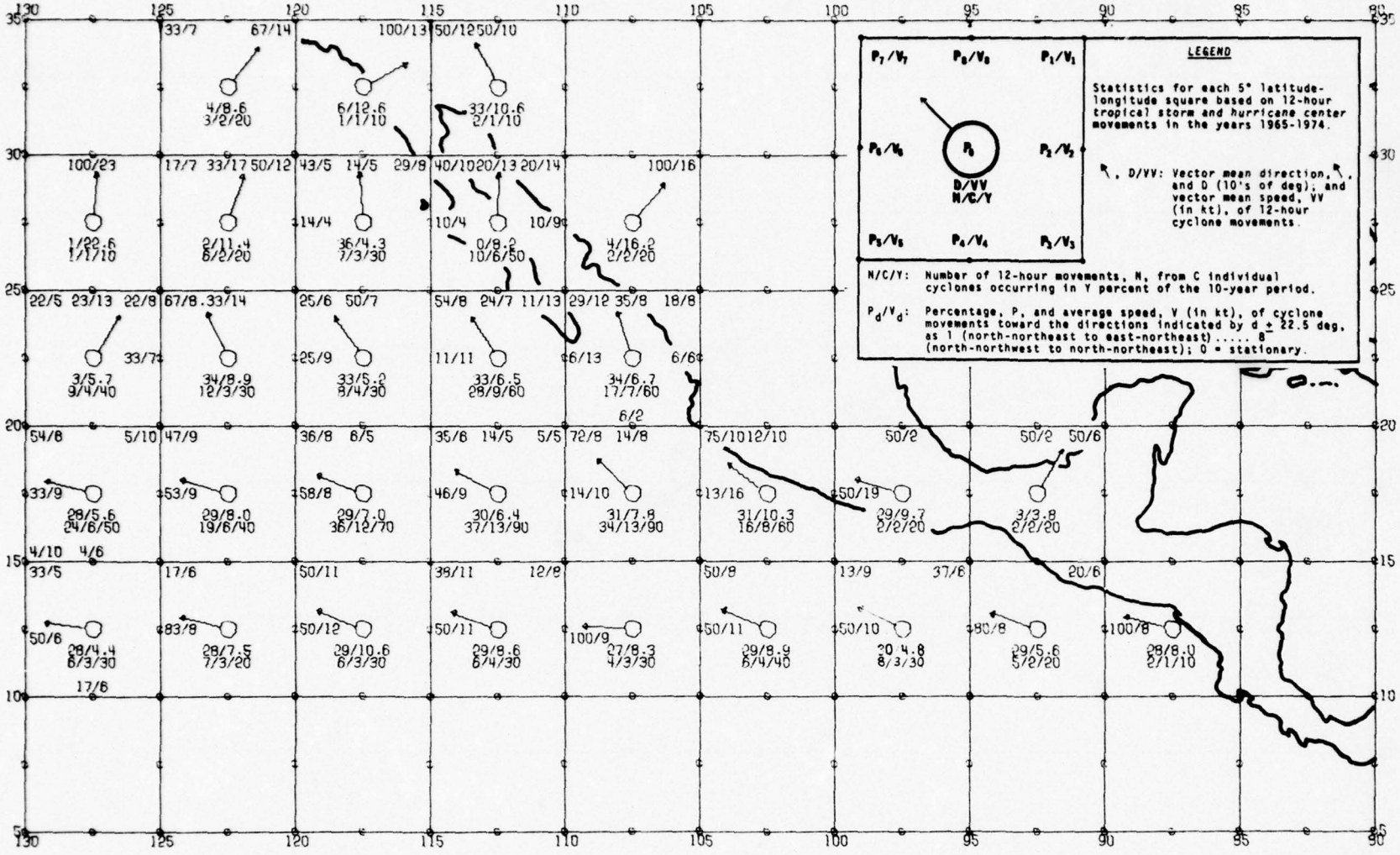


Figure 4-20b. Twelve-hour movement analysis, September, eastern section.

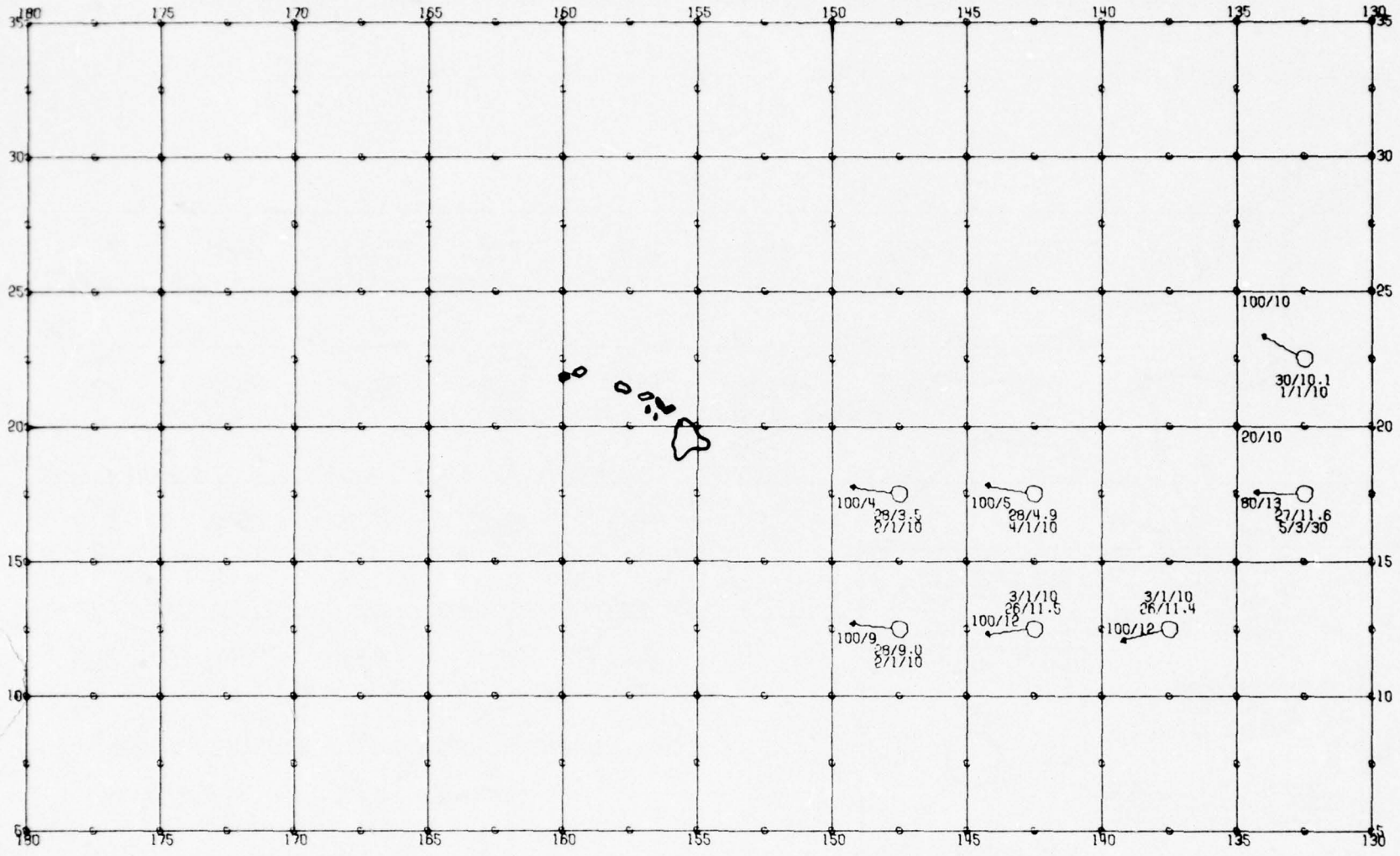


Figure 4-21a. Twelve-hour movement analysis, October, western section.

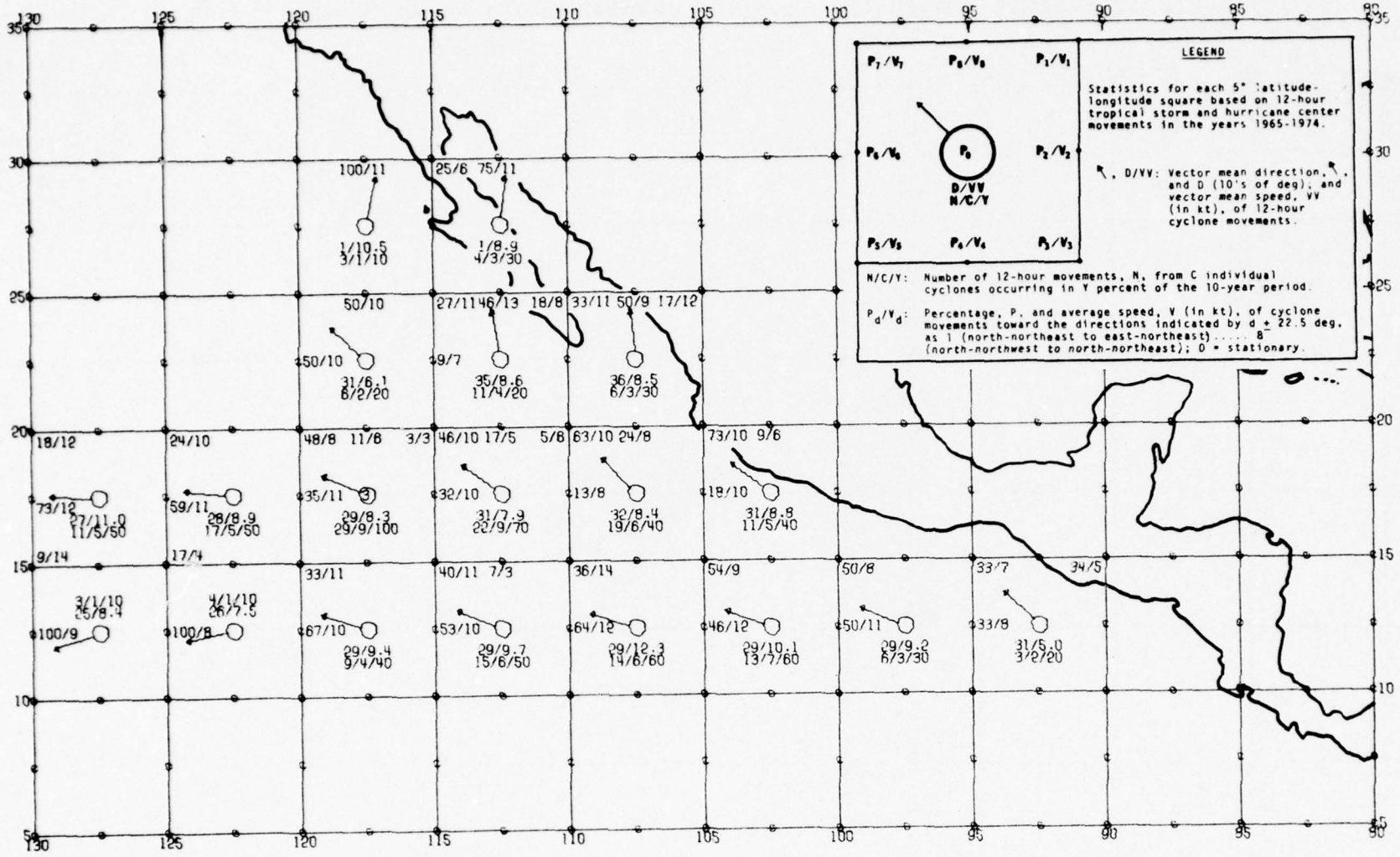


Figure 4-21b. Twelve-hour movement analysis, October, eastern section.

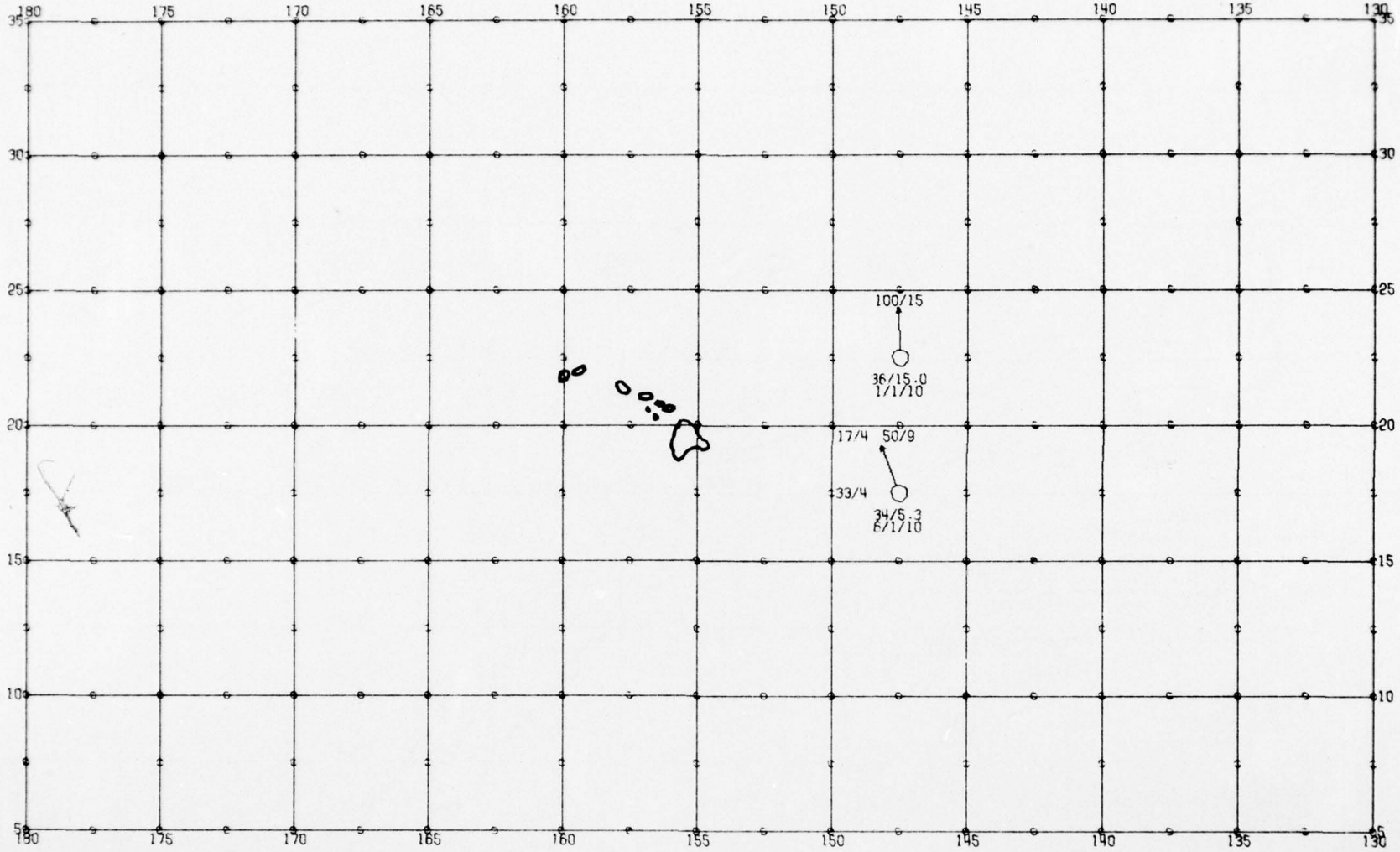


Figure 4-22a. Twelve-hour movement analysis, November, western section.

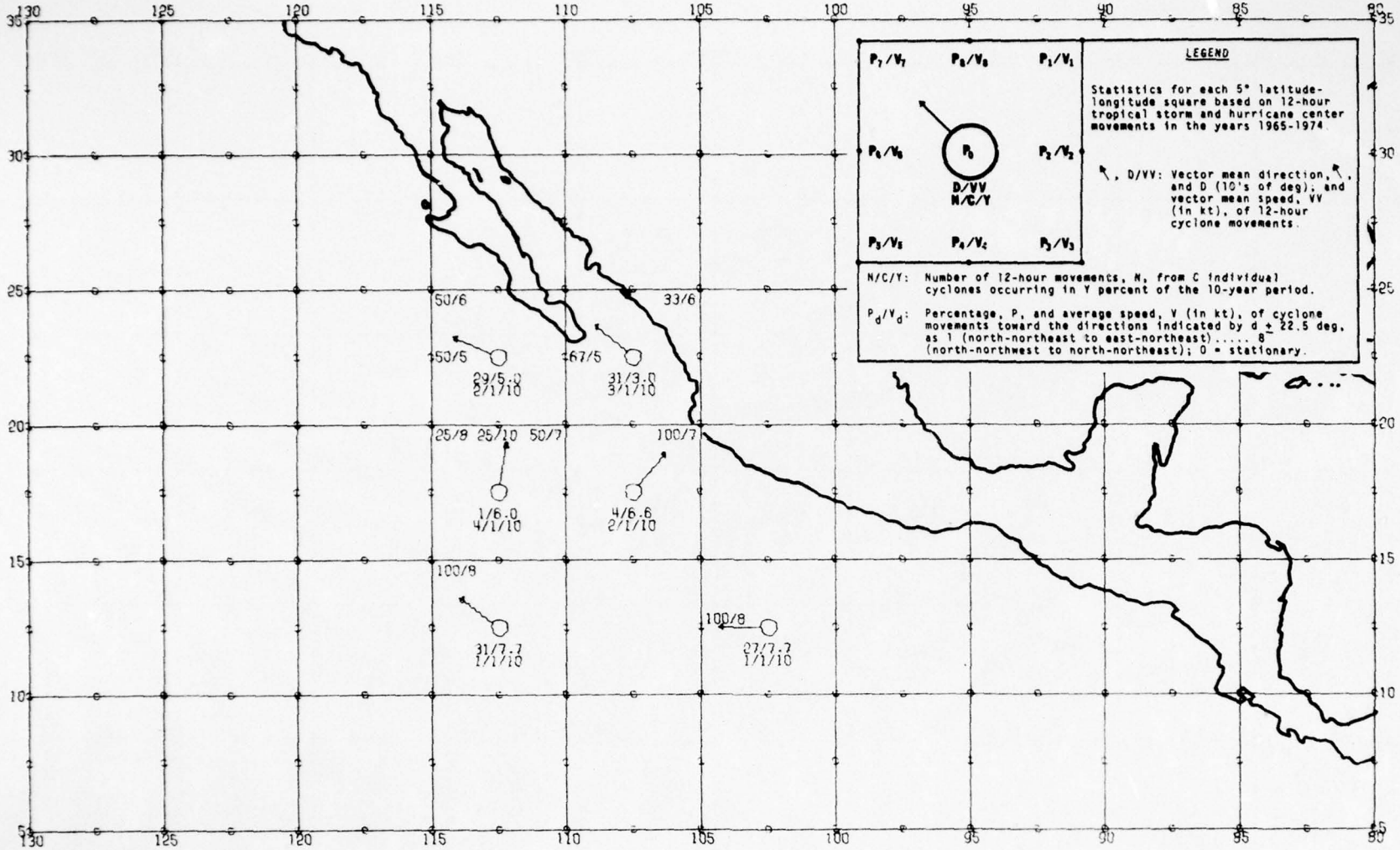


Figure 4-22b. Twelve-hour movement analysis, November, eastern section.

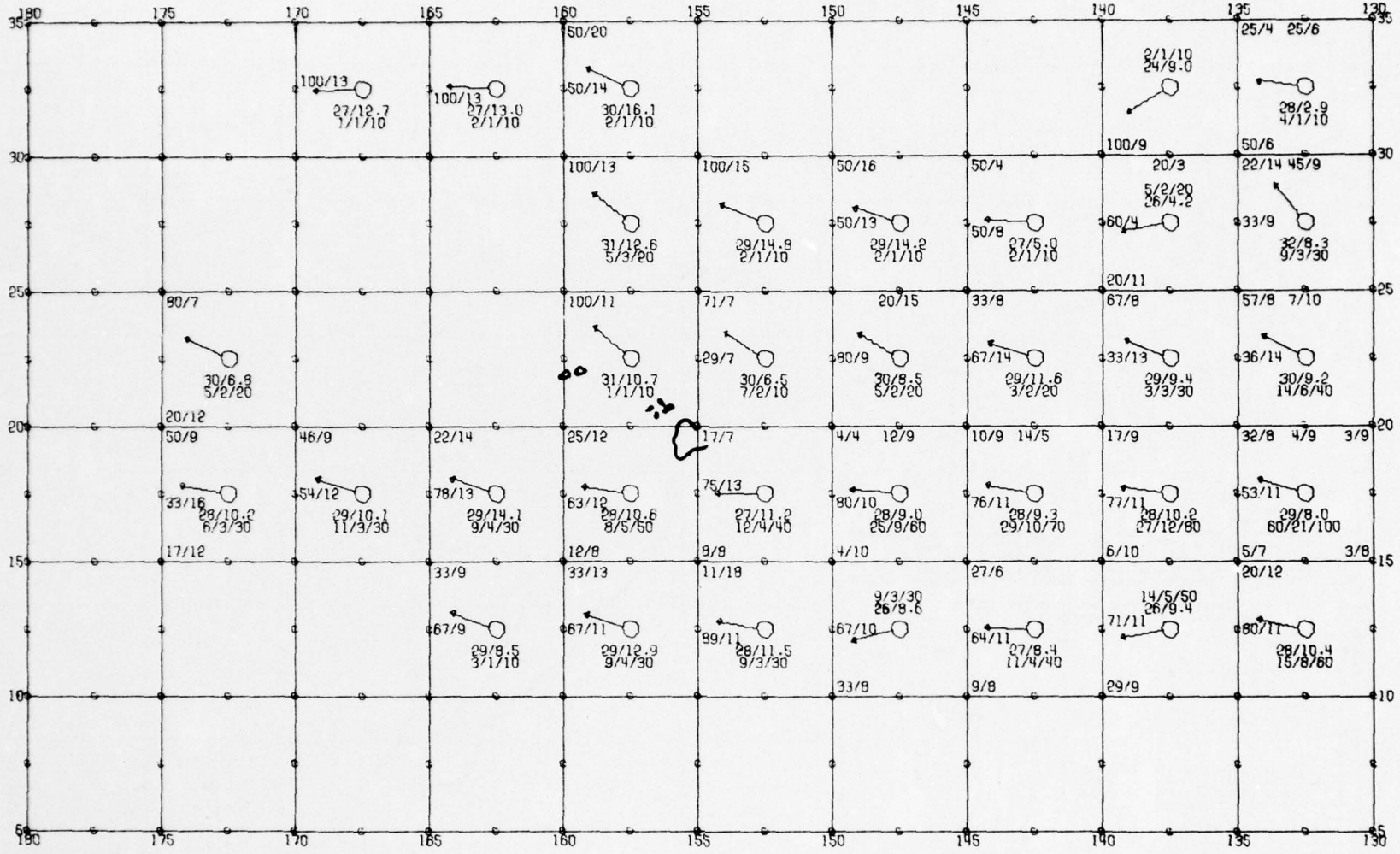


Figure 4-23a. Twelve-hour movement analysis, Annual, western section.

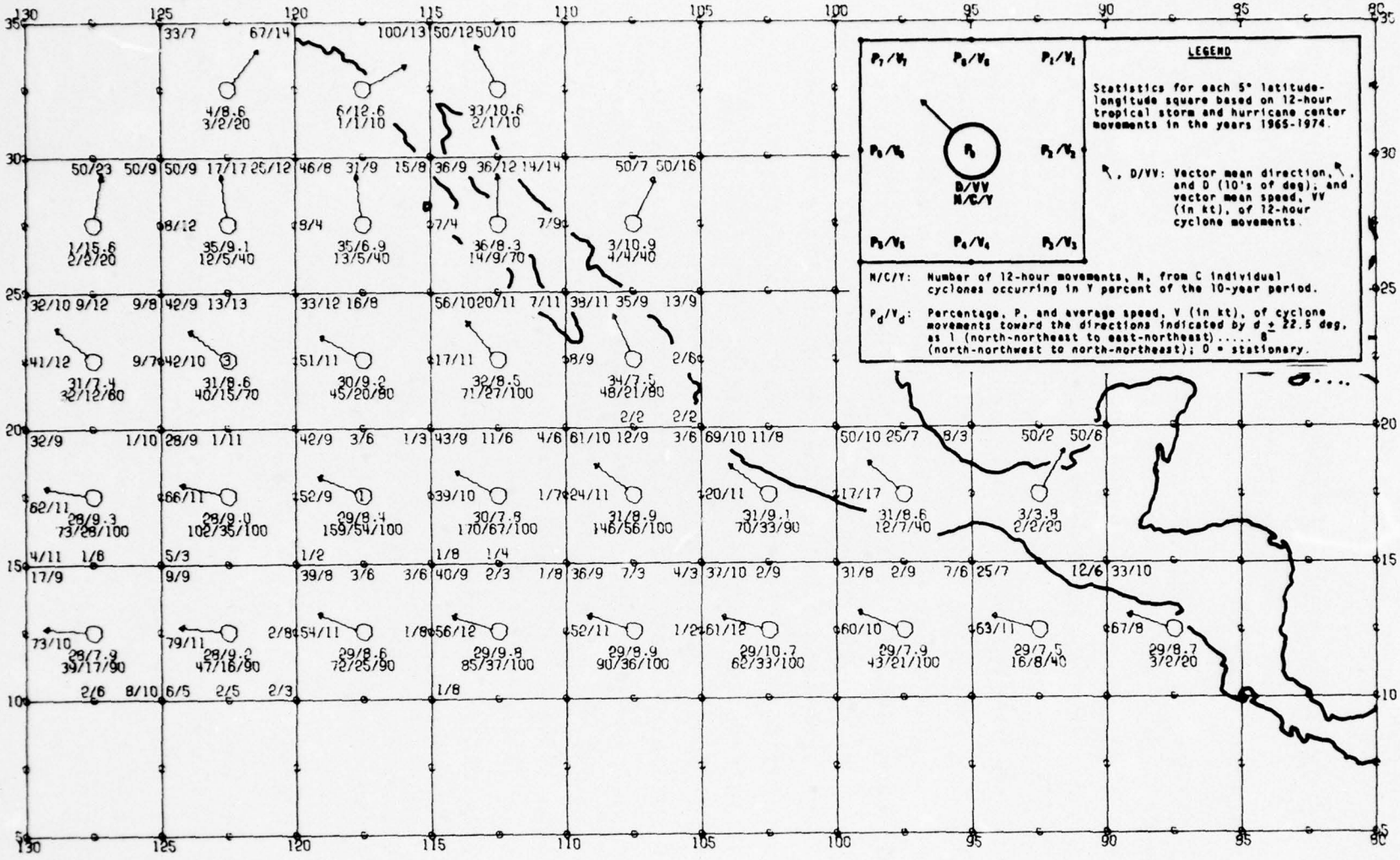


Figure 4-23b. Twelve-hour movement analysis, Annual, eastern section.

5. FORECASTING EASTROPAC TROPICAL CYCLONES

5.1 INTRODUCTION

Responsibility for forecasting tropical cyclones in EASTROPAC rests with the National Weather Service's Eastern Pacific Hurricane Center, Redwood City, CA (for the area east of 140° W), and Central Pacific Hurricane Center, Honolulu, HI (for the area 180° to 140° W) (U.S. Department of Commerce, 1976). Until recently, the main approach for forecasting initiation, movement, intensity and dissipation of EASTROPAC tropical cyclones has been mostly a subjective combination of climatology (see, for example: Atkinson, 1971; Baum, 1975; Crutcher, 1973; Crutcher and Quayle, 1974; Gray, 1975; Hansen, 1972) and persistence, with experience playing a major role in formulating the forecast. For estimates of motion, the recent introduction of two objective schemes (MOHATT and EPANALOG) holds promise of improved forecast accuracy. MOHATT is an automated statistical steering model that utilizes diagnostic and prognostic Fleet Numerical Weather Central model-output steering fields (Freeman, 1972; Renard and Harding, 1975). MOHATT has not reached an operationally useful point in EASTROPAC at this time, although it has demonstrated skill exceeding the official forecasts in the North Atlantic area. EPANALOG, an analog approach, is operationally ready and has shown accuracy excelling that obtainable by existing EASTROPAC methods; it is discussed further below.

5.2 FORECASTING TROPICAL CYCLONE MOTION BY AN ANALOG SCHEME

In 1974, Jarrell, Mauck and Renard (1975) developed an objective analog scheme to forecast the motion of EASTROPAC tropical cyclones. The scheme, known as EPANALOG, searches historical tropical cyclone movement records for situations statistically analogous to the one at hand. A composite of

the subsequent behavior of these selected analog cyclones is then used to derive the forecast of the current tropical cyclone.

Output includes cyclone-center position as well as 50% probability ellipses for 24-, 48-, 72- and 96-hour forecast intervals. Figure 5-1 illustrates a typical computerized EPANALOG input/output message along with a plot of the output. The forecasts have been produced operationally by Fleet Weather Central, Pearl Harbor, Hawaii, since the beginning of the 1975 season.

For an area like EASTROPAC where tropical cyclones are numerous but seasonal, and behavior is considered to be fairly regular, an analog approach to forecasting is quite successful. Figures 5-2, 5-3 and 5-4 depict comparative analog (EPANALOG), official (as issued by the National Weather Service Forecast Office, Redwood City), and persistence (linear extrapolation of 24-hour history) forecast statistics for 1973 and 1974 by forecast interval (24-, 48-, 72- and 96-hr), stage (depression, storm, hurricane) and track (before and after recurvature). Stage and track characteristics are specified for the verification time of the forecast.

Except for the after-recurvature forecasts, EPANALOG accuracy generally excels that of official and persistence for all stages and track types at all forecast intervals. The accuracy of the analog scheme is particularly evident in the case of the hurricane stage. Here, the analog forecasts represent more than a 20% improvement over the official forecasts. The official forecaster did not have access to the EPANALOG forecasts in the 2-year period summarized here.

Considering stage (Figure 5-3) the poorest forecast results for all three types of forecasts (official, EPANALOG, persistence) generally occur in the depression and storm stages of the cyclone. One reason for this result is the positive correlation of initial position accuracy and cyclone

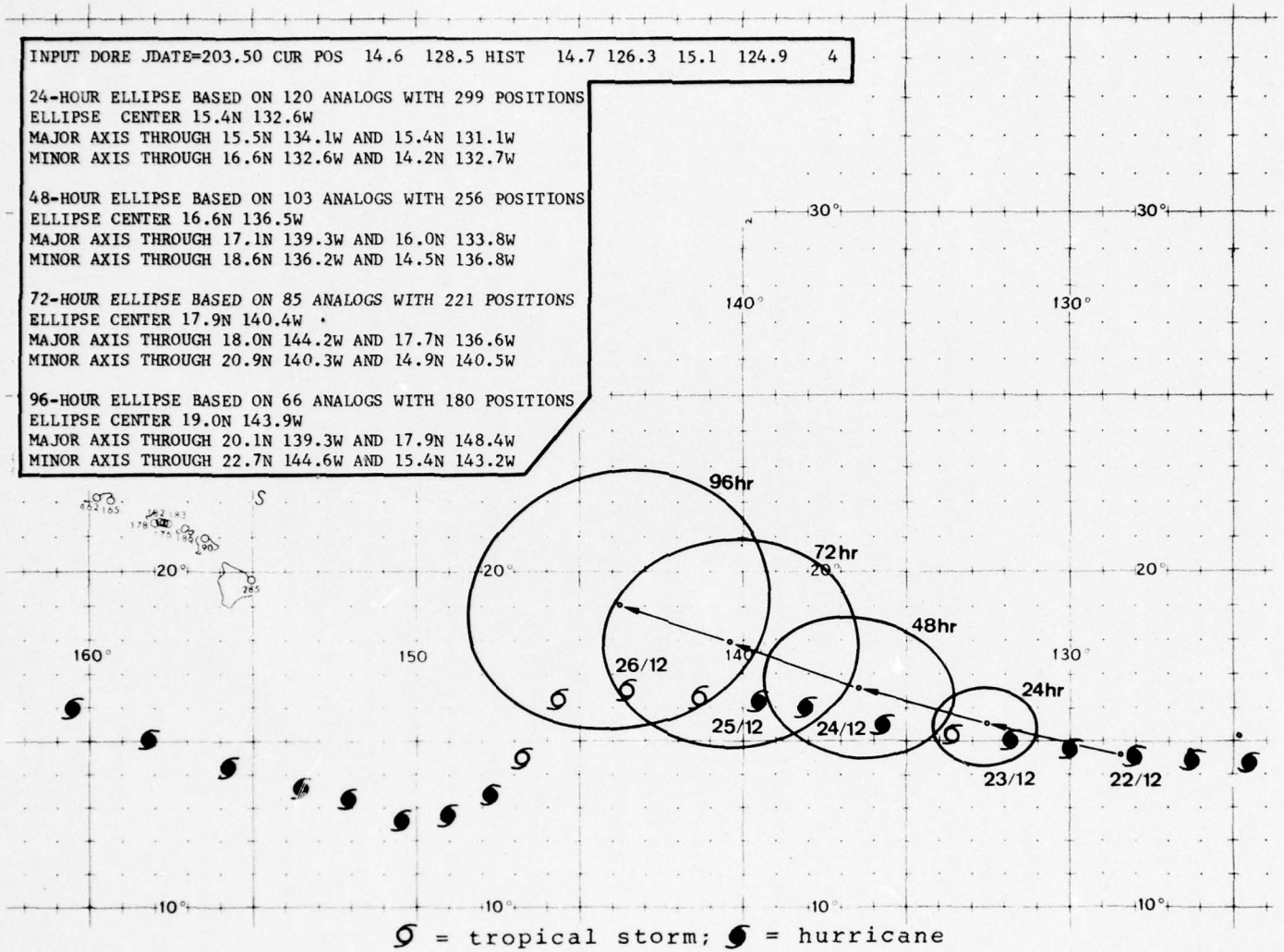


Figure 5-1. The 24-, 48-, 72- and 96-hour analog forecasts of Hurricane Doreen, starting from the operational 1200 GMT 22 July 1973 position. The most probable forecast positions are centers of 50% probability ellipses. Best-track tropical cyclone locations at 12-hour intervals, coded for stage, are shown for comparison. Insert: Associated computer-produced EPANALOG forecast message.

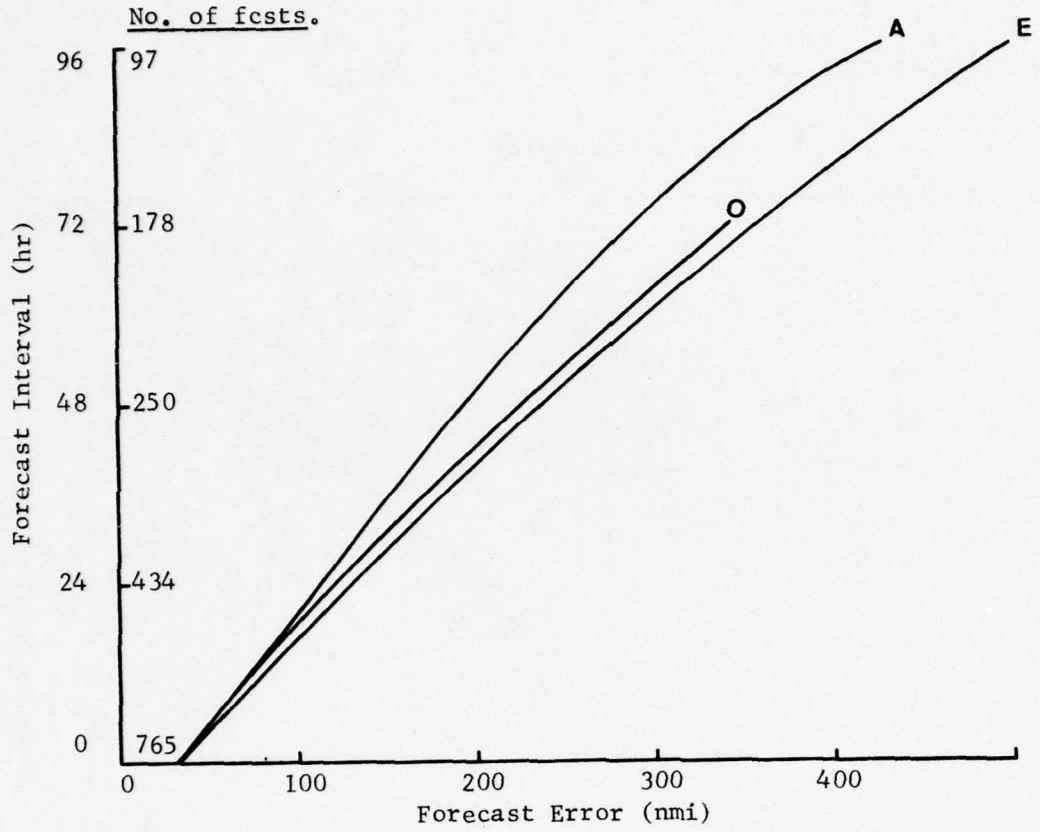


Figure 5-2. EPANALOG (A), Official (O) and 24-hr linear extrapolation (E) forecast errors as a function of forecast interval (0, 24, 48, 72, 96 hr), eastern North Pacific Ocean, 1973/74. 96-hr forecasts for 1974 only. Error at 0 hr represents average difference between all available operational and best-track positions in the two-year period.

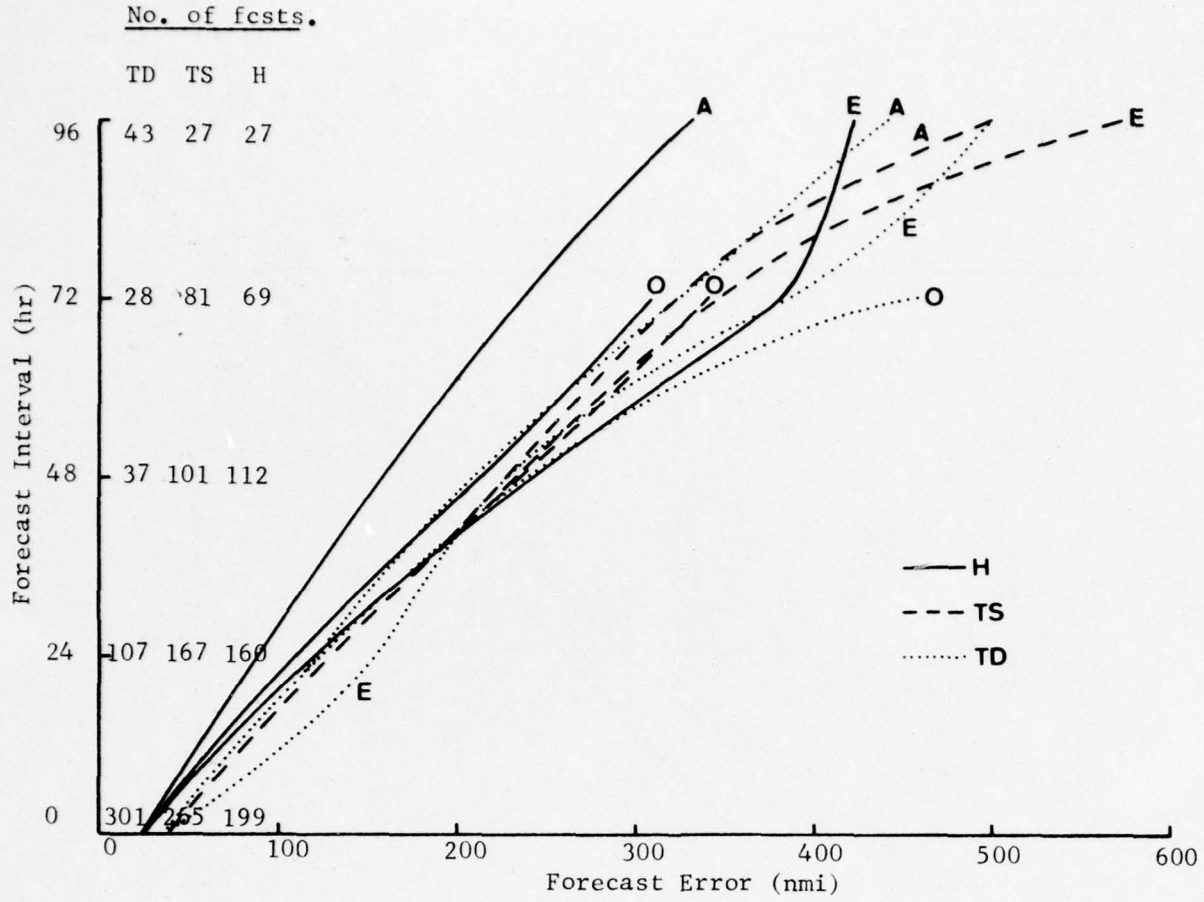


Figure 5-3. EPANALOG (A), Official (O) and 24-hr linear extrapolation (E) forecast errors as a function of forecast interval (0, 24, 48, 72, 96 hr), stratified by tropical cyclone stage at verification time (H = hurricane, TS = tropical storm, TD = tropical depression), eastern North Pacific Ocean, 1973/74. 96-hr forecasts for 1974 only. Errors at 0 hr represent average differences between all available operational and best-track positions in the two-year period.

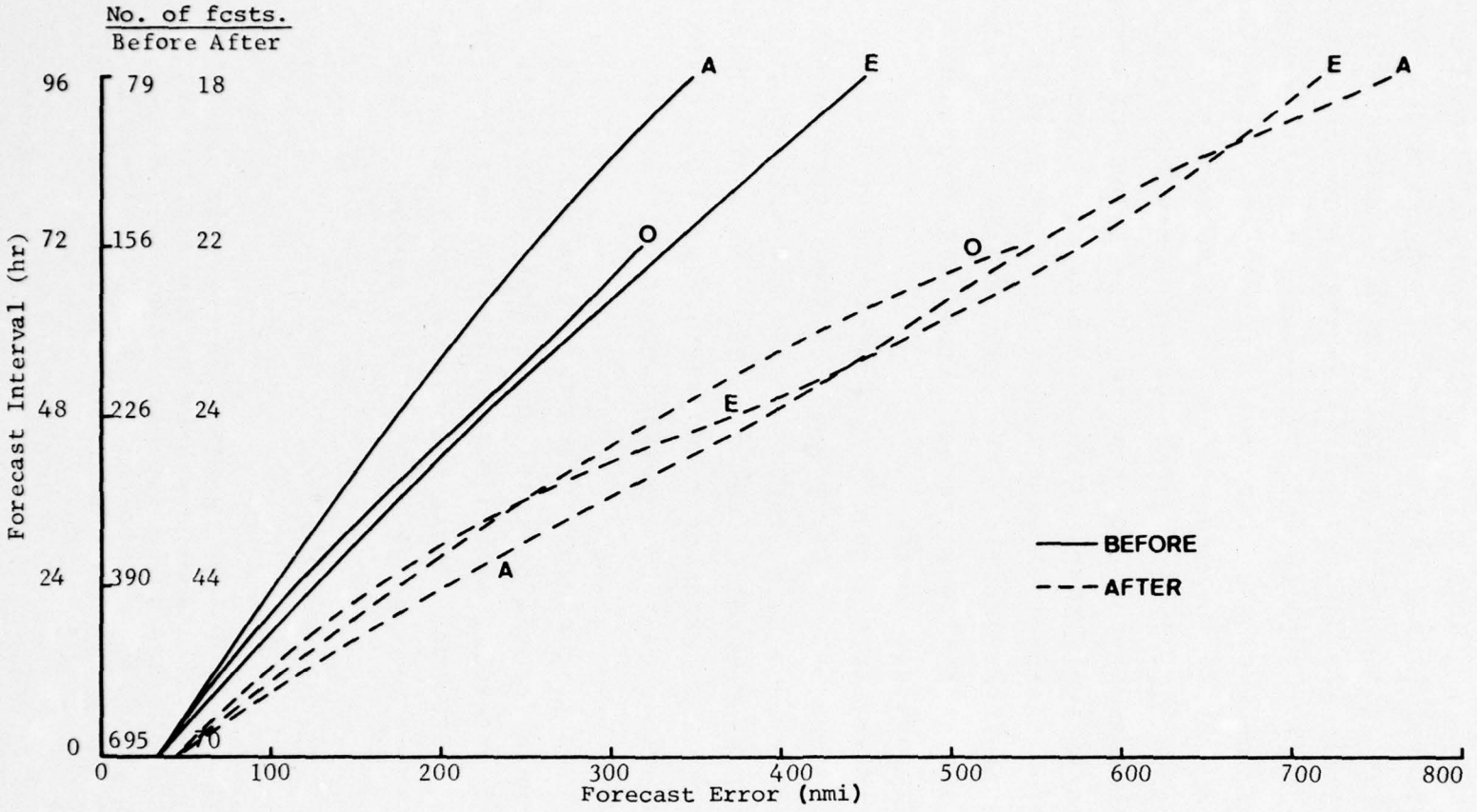


Figure 5-4. EPANALOG (A), Official (O) and 24-hr linear extrapolation (E) forecast errors as a function of forecast interval (0, 24, 48, 72, 96 hr), stratified by tropical cyclone track (before = before recurvature; after = after recurvature), eastern North Pacific Ocean, 1973/74. 96-hr forecasts for 1974 only. Errors at 0 hr represent average differences between operational and best-track positions in the two-year period.

intensity (stage). (Note the position errors at the zero-hour forecast interval (i.e., initial time) in Figure 5-3, especially for hurricanes versus a combination of depressions and storms.)* A closely related reason derives from the regularity or smoothness of the track which correlates positively with the intensity of the cyclone. The poorly forecasted recurvature tracks are generally for depressions or storm stages. A complication in clearly assigning reasons for stage-related forecast behavior is the fact that the depression and storm stages are relatively short-lived on the average (see Table 2-1), and since stage in Figure 5-3 is assigned by that existing at verification time, the peculiarities associated with these assigned stages are not necessarily representative of the whole forecast interval.

After-recurvature tropical cyclone tracks are notoriously difficult to forecast in any ocean. In the eastern North Pacific (Figure 5-4) such tracks represented only about 13% of the 24- to 96-hour forecast cases in 1973 and 1974. Decisions based on forecaster experience are particularly successful for such tracks, as noted from a comparison of official and EPANALOG accuracy.

Initiation time of the forecast is also related to accuracy. Both for the official and EPANALOG forecasts, for any forecast interval, accuracy is generally best for forecasts initiated at 1800 GMT. Those starting at 0000 GMT are second best while those started at 1200 GMT are poorest. The

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*The fact that initial position errors are nearly the same in the case of storms compared to depressions arises from what is regarded as an apparent reluctance to modify 1974 operational depression positions in the post-season best-track processing. In 1973, the positive correlation mentioned here was quite evident.

accuracy difference between best and poorest is especially large for 24-hour forecasts (29% for official and 25% for EPANALOG). These results relate to cyclone position accuracy, which relates to the time of day. A combination of maximizing conventional ship reports, satellite data and reconnaissance reports (when available) during local daylight morning and afternoon hours are responsible for the times associated with best forecast accuracy.

Accuracy of forecasts in the eastern North Pacific Ocean is comparable to that of other areas with tropical cyclones. Regularity of life cycle compensates for scarceness of data and the lack of objectivity in forecasting approach in the area. Relative to the 1973 operational forecasts of the western North Pacific and North Atlantic areas, the 1973 EPANALOG forecasts for the EASTROPAC area were found to be of equal caliber at 24 hours and superior in relative accuracy thereafter (Jarrell, Mauck and Renard, 1975).

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